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Notices of the Royal Aëronautical Society.

Examinations.

On another page will be found the Syllabus of the Society's Examination for Associate Fellowship. This syllabus together with the rules and regulations for the admission of Fellows and Associate Fellows will shortly be available as a pamphlet. Intending candidates are reminded that the first examination will be held in April, 1922.

"Rigid Airships."

It is regretted that through an oversight the fact that Mr. J. L. Bartlett's two lectures on "Rigid Airships," printed in the July number of the Journal, were delivered before the Scottish Branch was not stated.

Scottish Branch.

The following have been elected to the Scottish Branch:—

Member.—Capt. A. Douglas S. Barr.

Associate Members.—A. P. Donald, Capt. A. McR. Moffatt.

Lecture Programme.

The programme of lectures for 1921-1922, being the Fifty-Seventh Session since the inauguration of the Society, so far as at present arranged is as follows:—

Nov	3.	"Manœuvres of Getting Off and Landing." R. M. Hill.
,,	17.	"Requirements and Difficulties of Air Transport." Col. F. Searle.
Dec.	1.	"Design of a Commercial Aeroplane." Capt. G. de Havilland.
,,	15.	"Development of the Fighting Aeroplane." Capt. F. M. Green.
1922.		
Jan.	5.	"Specialised Aircraft." Wing Comdr. W. D. Beatty.
,,	12.	Juvenile Lecture. (Lecturer to be announced later.)
,,	19.	"Aeroplane Installation." Brig.-Gen. R. K. Bagnall Wild.

Feb. 2. "Radiological Research and the Examination of Materials." Dr. V. E. Pullin.
,, 16. "Methods of Instruction in Aeroplane Flying." Squadron Leader C. F. A. Portal.
Mar. 2. "Testing Aircraft to Destruction." W. D. Douglas.
,, 30. "Airships." (Lecturer to be announced later.)
Apl. 6. (Subject to be announced later.) Mons. Breguet.

The lectures will be held in the Theatre of the Royal Society of Arts, Adelphi, at 5.30 p.m.

W. LOCKWOOD MARSH,
Secretary.

ASSOCIATE FELLOWSHIP.

SYLLABUS OF EXAMINATIONS

(In accordance with Clause VI. of the Regulations).

PART I.

(General Educational Qualification.)

ENGLISH (One Paper).—A general paper comprising questions in Geography, History and Literature,

or

French, German, Italian, Spanish } Each paper will contain passages to be translated into English from books not previously prescribed, together with questions in grammar and a passage to be translated from English into the language selected by the candidate.

ELEMENTARY MATHEMATICS (One Paper).

Arithmetic.—The principles and processes of arithmetic applied to whole numbers and vulgar and decimal fractions. The metric system. Approximations to a specified degree of accuracy. Contracted methods of multiplication and division of decimals. Ratio and proportion. Percentage. Averages. Practical applications of arithmetic. *Algebra.*—Symbolical expressions. Equations of the first or second degree (and problems leading thereto). Square root. Graphs of simple rational integral algebraic functions. Arithmetic and harmonic progression. Geometric progression. Theory of indices. Logarithms. Theory and use of the slide rule. Binomial theorem for a positive integral index. *Geometry.*—The subjects covered by Euclid I.-IV. with simple deductions, including easy loci and the areas of triangles and parallelograms of which the bases and altitudes are given commensurable lengths. (Euclid proofs will not be insisted upon.) *Trigonometry.*—Up to and including the solution of triangles, together with the practical solutions of triangles and applications, and numerical examples involving the use of logarithmic and other tables.

PART II.

(Technical Qualification.)

One Paper in any two of the following subjects.

(*a*) STRENGTH AND ELASTICITY OF MATERIALS AND THEORY OF STRUCTURES.

Strength and Elasticity of Materials.—Physical properties and elastic constants of metals and timber. Relation of stress and elastic strain. Limit of elasticity. Yield point. Young's modulus. Shear modulus. Poisson's ratio. Compression, shear and torsion. Thin cylindrical shells. Strength and deflection in simple cases of bending. Beams of uniform resistance. Suddenly-applied loads.

Ultimate strength with different modes of loading. Plasticity. Working stress. Phenomena in an ordinary tensile test. Stress-strain diagram. Elonga-

tion and contraction of area. Effects of hardening, tempering and annealing. Fatigue of metals.

Forms and arrangements of testing machines for tension, compression, torsion, bending and hardness. Notched-bar testing machine. Instruments for measuring extension, compression and twist. Forms of test pieces and arrangements for holding them. Influence of form on strength and elongation. Methods of ordinary commercial testing. Percentage of elongation and contraction of area. Test conditions in specifications for metallic and non-metallic aircraft materials.

Theory of Structures.—Graphic and analytic methods for the calculation of bending moments, shearing forces and deflection, and of the stresses in individual members of framework structures, loaded at the joints. Principle of least work. Redundant frames. Stresses suddenly applied and effects of impact. Buckling of struts. Combined stresses. Theorem of three moments with its aeronautical generalisation. Riveted and pin-joint girders.

(*b*) AERODYNAMICS.

Physical properties of the atmosphere. Viscosity. Flow of air past immersed bodies. Streamlines and eddies. Distribution of surface pressure in important cases and calculation of resultant force therefrom. Bernoulli's theorem.

Simple laws of resistance. Fairing of form. Skin friction. Pitot tube. Theory of physical dimensions applied to similar motions.

Applications of the principle of dynamical similarity in aeronautics.

Arrangement and justification of model experiment.

Apparatus and methods for accurate work in the aeronautical laboratory. Mutual interference of air-flow by adjacent bodies. Reduction of results. Forces and moments on bodies inclined to the relative wind. Centre of pressure. Axes of reference. Nomenclature.

Properties of aerofoils. Biplanes and triplanes. Scale effects. Downwash.

Blade element theory of airscrews. Froude's theory and translational inflow. Lay-out and design.

Types and construction of aeroplanes and airships. Controls. Equilibrium.

Steady flight in straight line, horizontal circle, helix. Manœuvres. Load factor.

Comparison of experimental data and application to aircraft design. Computation of total resistance. Power curves and analysis of performance.

Elements of stability. Nature and definition. Functions of stabilising surfaces. Phugoid oscillations. Records of full-scale experimental work.

Full-scale data.

(*c*) HEAT ENGINES.

Internal Combustion Engines.—Combustion and explosion of inflammable gases and vapours in air. Pressures and temperatures of explosion at different initial pressures. Variable specific heat. Effect of combustion chamber form and materials on performance. Effect of compression. Effect of altitude.

Four-stroke engines. Two-stroke engines. Arrangements of inlet and exhaust valves. Valve timing. Electrical ignition. Piston design. Diesel engines. Ignition by compression temperatures. Petrol engines. Carburettors.

Stresses due to inertia of moving parts. Balancing of engines. Valve gear diagrams. Speed reduction gears. Air and water cooling. Fuels and lubricants. Lubrication. Petrol systems.

Theory of Heat Engines.—Thermodynamic laws. Internal and external work. Graphical representation of changes in the condition of a fluid. Theory of heat engines working with a perfect gas. Air- and gas-engine cycles. Reversibility. Conditions necessary for maximum possible efficiency in any cycle. The Carnot cycles. Actual heat engine cycles and their thermodynamic losses. Testing of heat engines and the apparatus employed.

(*d*) METEOROLOGY AND NAVIGATION.

Meteorology.—Nature of atmosphere. Circulation. Dynamical heating and cooling. Temperature distribution. Measurement of altitude. Stratosphere and troposphere. Measurement of wind velocity at altitude. Gradient wind. Turbulence. Forecasting weather. Occurrence of fog. Atmospheric electricity. Precipitation and frost. Solar radiation.

Navigation.—Methods of aircraft pilotage. Measurement of ground speed, track and drift. Air speed and turn indicators. Magnetic compass theory and compass correction. Methods of measuring velocity of wind whilst in flight. Navy pattern and bubble sextants. Artificial horizons. Reduction of astronomical observations by position-line slide rules or by tables. Two-star tables. Plotting position lines for astronomical and for direction-finding wireless telegraphy observations. Use of gyrostats. Effect of periodic yaw, pitch and roll on navigational instruments.

(*c*) MATHEMATICS.

Hydrostatics.—Centre of pressure. Equilibrium of floating bodies. Metacentre. Steady rotating fluids.

Dynamics.—Rectilinear and circular motion. Centre of instantaneous rotation. Linear and angular momentum. Work and energy. Centre of mass and moment of inertia. Motion about a fixed axis. Dimensions of physical quantities. Impact and shock. Equations of motion of a rigid body with simple applications. Simple theory of the gyroscope. Elementary graphical statics.

Algebra.—Algebraic equations. Solution by Dunois theorem. Graaffe method. Summation of series in simple cases. Graphs and equations. Solutions by graphical methods. Solid geometry up to dimension cosines.

Differential and Integral Calculus.—Average velocity. Velocity at a point. Acceleration. Slope of a curve. Limits. Simple cases of maxima and minima. Differentiation of standard functions. Indefinite integration. Integration by change of variable. Definite integration. Areas and surfaces. Volumes. Mass centres. Moments of inertia.

Integration by parts and partial fractions. Maclaurin's and Taylor's theorems. Expansions for $\sin x$, $\cos x$, etc. Hyperbolic functions and their properties. Linear differential equations with constant coefficients, and their applications. Periodic motion. Forced vibration. Resonance. Torsional oscillations in shafting. Whirling of shafts.

(*f*) CHEMISTRY AND METALLURGY.

Chemistry.

Fabrics.—Linen, cotton and silk, characteristics and use. Properties required in material intended to be used for aeroplane coverings, hangars, parachutes, airships, etc. Methods of tests. Proofing of airship fabric, hangar canvas. Fireproofing of parachutes. Causes of deterioration of fabric and methods of protection. Cordage types and requirements. *Dope and Protective Coverings.*—General composition of acetyl and nitro-cellulose dopes. Functions. Methods of

prevention of deterioration. Chemical and physical tests. Composition and characteristics of protective coverings. *Fuels* for internal combustion engines from light spirit to heavy oil. Alcohol. Synthetic fuels. Chemical and physical tests. *Adhesives.* Casein and gelatine glue. Characteristics and uses as applied to aircraft. Chemical and physical tests. *Oils.* Characteristics of oils for use in aircraft engines, instruments, machine guns, etc. Causes of failure. Chemical and physical tests. *Rubber.*—Petrol proof tubing. Shock absorbers. Tyres. Airship fabric. Chemical and physical tests. *Anti-fouling liquids.*—Essential properties of liquids for use in compasses, radiators, buffers, etc. *Hydrogen for airships.*—Manufacture, properties and tests. *Paints and varnishes.*—Composition and properties required in paints and varnishes used for protection of metal and woodwork.

Metallurgy.

Methods of casting metals and alloys. Effects of casting temperature on structure and properties. Effects of types of moulds. Defects in castings.

Effect of forging, drop forging and rolling on structure and properties of cast metals.

Effect of cold working upon structure and properties of metals.

Steel.—Manufacturing processes and apparatus used. Nature and method of carrying out heat treatment including casehardening. Effect of heat treatment upon mechanical properties of steel. Relationship of chemical composition of steel to mechanical properties. Typical chemical composition of plain carbon and alloy steel. Mechanical properties at high temperatures. Properties of cold worked steel. Effects of impurities on the properties of steel. Corrosion and scaling and prevention of corrosion.

Non-Ferrous Metals.—Chemical composition of alloys of copper, zinc and aluminium. Mechanical properties of above alloys, etc., in the cast and (when possible) in the wrought condition. Effect of cold working on the mechanical properties of the above alloys, etc. Mechanical properties at high temperatures.

[NOTE.—Sufficient questions will be set in chemistry to allow of a candidate passing on this paper without taking any questions in Metallurgy, and vice versa.]

PROCEEDINGS.

ELEVENTH MEETING, 56th SESSION.

The Eleventh and last Ordinary Meeting of the Fifty-Sixth Session took place in the Hall of the Royal Society of Arts, London, on Thursday, March 17th, 1921, Major A. R. Low presiding.

The CHAIRMAN said he needed no words to introduce the Lecturer to that meeting. He would call on him at once to read his Paper.

Captain DAVID NICOLSON, A.M.I.N.A., M.I.E.S., A.F.R.Aë.S., then delivered the following Lecture :—

FLYING BOAT CONSTRUCTION.

The design and construction of light hulls and floats suitable for flying boats and seaplanes is a very highly specialised branch of shipbuilding. This being the case, all matters pertaining to same should be in the hands of naval architects. At a recent lecture before this Society, Commander Hunsaker, of the United States Navy, stated that British aircraft designers followed the naval architect's methods more than in any other country; he thought this was natural as he gave us the credit of being the first maritime power of the world. This may be perfectly true with regard to airships, but I cannot endorse his opinion that the majority of flying boats built in this country show the impress of the trained hand of a naval architect. I do not imply that the American boats are superior to ours, as for instance, a large American boat with twin engines built in the United States, which we used for the North Sea patrol, was by no means typical of good boat-building; there were no less than four consecutive planks butted—not even scarfed—on the same timber, which had a siding of $\frac{3}{8}$in., the line of butts being in line with the step where the boat was naturally weakest.

The Curtis boat, as originally built, was wall-sided, *i.e.*, without projecting side fins to the front step and planing bottom, but as it experienced difficulty in getting off the water, the breadth of the step was increased by adding fins, thereby improving the planing efficiency, although the fins in service were very liable to damage.

American built boats were later on imported in considerable numbers, but although the workmanship and materials were much improved, they were still weak owing to lack of continuity in the structural design, and frequent damages were reported, until at length the whole bottom had to be stiffened by timbers and stringers.

Boats of the " F " type which followed were a great improvement on the original type, but as in the previous boats, the bottoms gave trouble owing to the faulty keel and bottom construction.

For the past two years many builders have been debating about the construction of flying boats. On the one side it has been contended that flying boats should be built as light as possible, and that there should be no restriction whatever placed upon the designer in the matter of the construction. In support of this it was said that the designer must of necessity build his hull strong enough, otherwise she would lose her shape. It would also be very unwise to tie a clever designer's hand with a more or less hard and fast table of scantlings.

The arguments on the other hand were of a purely practical nature. It was maintained that the keenness of competition was such that, if lightness of construction were unlimited, most flying boats would be weak, and probably unseaworthy. The same vexed question of scantlings was much discussed a few years ago by yacht-builders as to whether racing yachts should be classified by Lloyds and built under their rules. Arguments on similar lines to the above were put forward by the two schools of thought, and after the International Conference of 1906, the yachtsmen of Europe decided to abandon all theoretical contentions, and they passed a rule that every yacht racing under the rules of the International Yacht Racing Union must be classed either by Lloyds Register of Shipping or other corporation. And now, in my opinion, similar rules should be drawn up for the construction of flying boat hulls. In coming to this conclusion, it must not be supposed that designers would place themselves unreservedly in the hands of the classification committee, as in the case of yacht-building hard and fast jurisdiction or monopoly of surveying the building can be guarded against. Every racing yacht must be built according to the rules and scantling tables, but the choice of material is left to the owner or builders, provided it will pass the inspectors. Again, provided the yacht obtains the class " R," the owner is not obliged to obtain the class for her for any special term of years. Thus one yacht may be classed " 10 R," another " 12 R," and another " 14 years R," and all would be equally eligible under the Y.R.A. rules. Regulations similar to the foregoing could also apply to boats built for civil aviation but with a much shorter period.

In some cases floats were built and passed for civil aviation, and when similar floats were required for the services they had all to be strengthened, many extra fastenings put in the butt joints, heavy butt straps fitted, and special diagonal stiffeners put on the bulkheads. If the floats required all the extra strengthening for the services, surely for civil work, when probably more lives were depending on these floats, they should have been made to the same specification; or if they had been passed, a certificate for only a few months should have been given. Again, the gusset pieces of three-ply were only glued and tacked to the frames, and when the services required the floats they had all to be through fastened and the edges protected, and if this had been carried out on the civil aircraft, a class for, say, two years, could then have been granted. Extra periods of classification should be granted according to the fastenings and materials used. In granting certificates for airworthiness in civil aircraft, the technical department might include seaworthiness for all flying boats and also classify them yacht fashion and give a period when the boat should again be surveyed.

If a boat is built to rules, the class is determined by the scantlings and equipment, and is adopted for the purpose of insurance in some cases. In building to a class, the scantlings of all the structural parts are fixed by the table of rules, thus ensuring uniformity of weight of structure. If we consider the case of the " F " type of boat, it will be seen that there is no uniformity of weight of structure, the nose is much too heavy, the stringers too closely spaced, while the timbers and bottom are much under strength. If we are to carry passengers in flying boats, then their safety if they have to alight at sea must be considered.

Since longitudinal damage is most destructive as regards loss of buoyancy, the criterion of risk should be measured longitudinally and under water. Therefore some regulations should be drawn up by means of a criterion of risk which involves a longitudinal under-water tear extending for a constant percentage of the length of the boat.

All interested in the design and construction are seriously concerned with the present unsatisfactory position of the watertight sub-divisions and bulkheads. At a paper read by the late Major Linton-Hope before this Society, much discussion

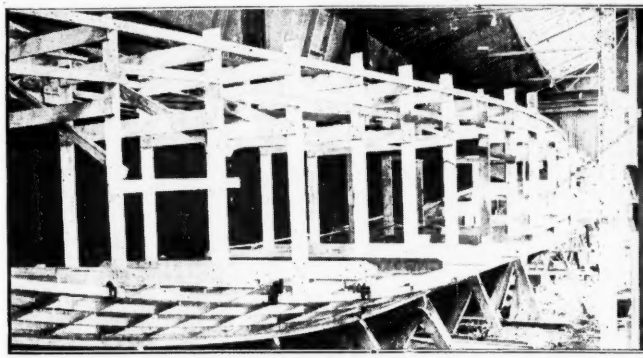


Photo No. 1.—F boat, showing wrong method of holding moulds together.

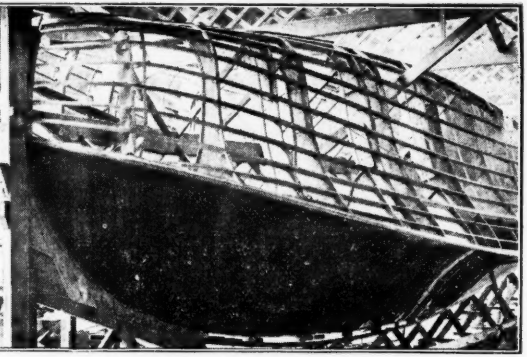


Photo No. 2.—N4, showing web frames and longitudinals.

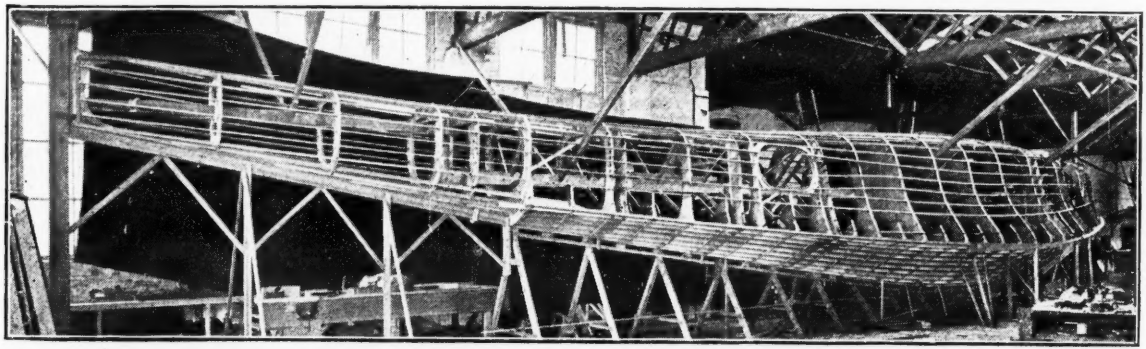


Photo No. 3.—N4 Atalanta. Skeleton view showing longitudinal system.

took place on this very important subject, and yet up to the present no action has been taken to remedy same. The principal difficulty is to fit a bulkhead that will stand the inrush of water, and yet be resilient to pant if the hull is resilient. In my opinion this can be got over by adopting lap or expansion joints instead of edge to edge or tub joints as is now practised.

Bulkheads are useful in three ways—as W.T. divisions, as fire screens, and as structural diaphragms. In the first capacity they may confer immunity from sinking, for should water enter the boat as a result of damage to the skin, it may be confined to the one space; in the second they may, should a fire occur, confine the conflagration to the one space, facilitate its extinction and limit the damage. In the foregoing two capabilities, their usefulness is only potential, but in the third, as structural diaphragms, they are at all times beneficial, for by uniting the bottom sides and deck, they are most efficient in checking any tendency to alteration in the form of the transverse sections, due to racking or panting stresses. Although bulkheads give immunity from foundering, their capabilities in this respect are dependent on many circumstances. The sub-division of the hull must be such that if any compartment be flooded, the loss of reserve buoyancy will not cause the boat to sink. Also if the bulkhead be weakly constructed, it might collapse under the water pressure or it may not be thoroughly watertight. Again, the bulkhead must be built above L.W.L., for if not, as the water rose in the bilged compartment and the boat subsided, it would flow over and fill the adjacent holds. In the past flying boats these qualities do not seem to have been taken note of, and as far as I can see, the bulkheads only acted as structural diaphragms, and very poor specimens at that. Another point worthy of note would be the making of the centre keelson watertight, thus forming a sub-division right fore and aft.

I have not mentioned the alteration in trim due to the flooding of any compartment, as with the present small flying boats, this does not affect us very seriously, but when larger boats are built, this will have to be noted as it will regulate the position of bulkheads or the size of the various holds.

The subject of bulkheads covers such a large field, especially when fire-resisting material and construction is desirable, that it is not possible here to deal with it to any great extent. The same subject was for many years attracting the attention of shipbuilders, with the result that a special committee was appointed to draw up rules and methods of construction to secure the benefit of safety. It is my opinion that if such a committee was considered necessary for ships, a similar committee of naval architects should be appointed to deal with flying boat bulkheads.

Before touching upon the detail of construction, I think a few words on the "laying off" would not be out of place here. To illustrate the importance of the loft work, I should like to point out that it was owing to the bad laying off that many flying boats at the sea stations required individual trolleys for themselves which had to be specially shaped at the station to take one particular boat. If all these boats had been laid off by a naval architect who appreciates the fineness of the scrieve board lines, then the correct offsets supplied to each builder who would not have required to do any fairing in or out, and if the moulds had been properly held by ribands, all the boats would have been very close in shape. I am aware that many engineers and aircraft builders do not realise to what fine limits naval architects have to work when scrieving out the lines. I have often heard it stated that anything from $\frac{1}{4}$in. to $\frac{1}{2}$in. in or out did not matter, hence the reason for so many unfair boats. If a yacht-builder worked to these lines, I am afraid many of his racing yachts would be outclassed if she drew $\frac{1}{4}$in. more than her designed draft; and soon the builder would have to construct flying boats for the agents who consider that such fine lines are not necessary.

Aircraft manufacturers who have not had any experience in power boat building will find it essential to lay a mould loft floor if they intend building flying boat hulls, and when the floor is properly laid and painted, fair lines will be much more easily scrieved. In the first place, the sheer plan must be delineated on the floor, then the half breadth, and finally the body plan. When these have been scrieved and the thickness of plank removed, then the moulds for frames can be lifted direct, also the various moulds showing the shape of different parts of the hull, battens and templates giving precise information as to the sizes and disposition of the structural parts can then be lifted. These lines are very useful as they often dispense with the necessity of fitting a mock-up in the shops. When the moulds are made, the stocks have to be set to take same, and here many of the builders of flying boats placed these about one foot above the floor to find that when the boat was ready for rivetting they had to lift the whole hull and raise the stocks to a convenient height to allow the men to work under. The moulds now set in place on the stocks have to be kept in position by ribands, each riband running the whole length of the boat; here again many builders erred by fastening each pair of moulds together by small battens, as will be seen in

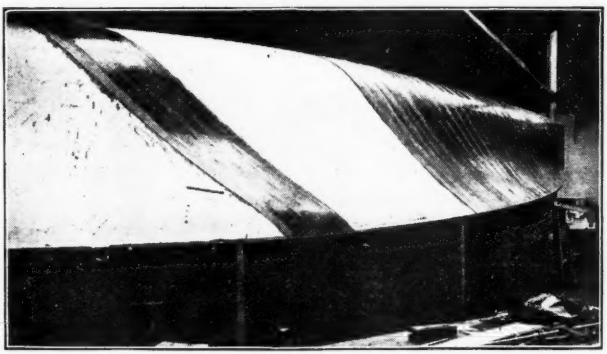


Photo No. 4.—N4 Atalanta. View from amidships, looking forward.

photograph No. 1, and then they wondered why the boat was not fair when she was planked up. A good example of this was seen in the F.5 boats, where many metal fittings were made to a jig by one firm to obtain good production, but this object was defeated as many of the fittings did not coincide with their structural part, therefore the various builders had then to make their own fittings to suit their particular lines.

The principal feature in many hulls is the skin; all the other structural parts are more or less subsidiary, their function being to support and stiffen it. The skin is stiffened by framework disposed transversely and longitudinally, and further the sides are united by beams to support same against collapse. The same total strengthening can be effected by heavy frames spaced at wide intervals or by numerous small frames spaced very closely, but these systems cannot, for practical reasons, be exceeded, as in the former if the frames were widely spaced and proportionately heavy, they might preserve the form of the hull as a whole, but they would not give sufficient local stiffness to the skin in order that it would not buckle between the frames. If the latter was carried to excess the ultimate result would be equivalent to a mere thickening of the skin. If made sufficiently thick it would be self-supporting, but owing to the excessive thickness it would be too heavy and useless for flying boats.

Before settling the scantlings of a hull, the most efficient disposition of material should be considered in conjunction with the duties the boat has to perform. The cost of construction should also be taken into account, and this is dependent to a certain extent on the quantity of material used and on the method of construction.

If the hull is built of few and heavy parts, it would involve less skilled labour, therefore would be much cheaper, but the hull built of more numerous parts, smaller, but efficiently formed, and disposed of for their more specialised duties, although the initial cost is more, is the better boat, as it will be lighter, and as carrying capabilities are so important, the extra first cost is justified.

In the usual type of hull the transverse frames form continuous ribs round the body, giving to the yielding skin the necessary lateral stiffness, and resist all stresses tending to alter the form of the transverse sections; however, this would give imperfect rigidity, as each one would be independent of the adjoining one, therefore, to give a combined and good resistance, they are united by the keelsons and side stringers. The boat's framework is thus composed of the transverses and longitudinals. The former, disposed in direct contact with the skin, constitute the main skeleton of the hull, the skin and other members being fitted to it as a groundwork. The keelsons and side stringers are fitted in continuous lengths within the transverse which form a supplementary skeleton; these are connected, not merely to the inner surface of the transverse frames, but extend intercostally between them so as to connect to the skin. The lower part of the transverse frames are made specially strong by having the floors connected to same, as the bottom is liable to severe pressures, both widespread and local, through the hull being docked in trol'eys or resting on the keel. For a similar reason the keelsons are made stronger than the side stringers; they also prevent the hull from hogging and sagging. The centre keelson being strongest of all, it might be regarded as the backbone of the hull.

It will be well to notice the difference and relative value of the two qualities, strength and stiffness, or rigidity. If we now consider the efficiency of the frames versus the stringers in stiffening the skin and supporting the sides against deforming forces, the transverse frames are short compared with the stringers as they only go from the keel to the deck, whereas the stringers run the whole length of the boat. It will be seen that the stringers, on account of their great length and consequent elasticity, cannot by themselves give useful resistance to widespread straining forces. Their principal duty is to give local support through their binding effect on the transverse frames, and when fitted intercostally, to stiffen the skin.

I think we might now consider the longitudinal versus transverse system of framing, or it might be stated which of the two kinds of stresses, longitudinal or transverse, should govern the boat's structural design. In the longitudinal system the main fore and afters run all the way of the boat, the web frames being cut out to allow them to pass. The web frames extend round the body of the boat, usually at fairly wide intervals, and are of such depth and massiveness that they form strong and almost inflexible supports to the sides, deck and bottom against all transverse forces. The supporting framework of the deck is arranged like that of the sides, light longitudinals being carried continuously through the deep cross girders. It may be said that in the foregoing system the deep web frames form the main skeleton of the hull, giving it all the necessary transverse strength to maintain unyieldingly its transverse shape. The longitudinals may be regarded as forming stiffening material for the skin and deck, giving these flexible surfaces the necessary rigidity to withstand all bending pressures acting between the supporting transverses (see Photo No. 2).

In comparing the longitudinal with the transverse arrangement of the light subsidiary frames, it will be seen that the heavy side stringers have been dispensed

with; it also possesses the advantage of stiffening the skin against the buckling tendencies brought about by the fore and aft compression stresses which accompany hogging and sagging of the hull Transverse frames and beams cannot prevent transverse buckling tendencies of the skin between them; to counteract this, they must be placed closely together or the skin increased in thickness. As the compressive stresses above mentioned are most acute at the top of the hull, it is evident that a longitudinal arrangement of beams is even more important than a longitudinal arrangement of side frames.

The longitudinal system is not only advantageous in increasing the longitudinal strength of the hull, but it also means a considerable reduction in weight which, while permitting additional carrying weight, also reduces the first cost.

One of the disadvantages of this system is that the numerous deep projections cause the interior space of hull to be broken.

A good example of the foregoing mentioned longitudinal system is the N.4 Atlanta designed by Mr. Charles E. Nicholson. His method omits the closely spaced transverse frames and beams; the transverse strength is obtained by fitting directly on the skin a series of strong web frames at widely spaced intervals. The longitudinals take the place of ribands, and only require to be secured to the transverses carefully and very little fairing is required (see Photo No. 3).

Photo No. 4 shows diagonal planking of the N.4 Atlanta built on the longitudinal system.

CONSTRUCTION—TYPE "F."

The construction of the "F" type is on the box-girder principle, with four longerons running right fore and aft. The keel, another fore and aft member, runs from the stern post right round the nose to form the stem and finishes at the gun ring. The keel and keelson combined with the floors form the backbone of the hull. I am of the opinion that the keel is of faulty design, for many boats were found to leak badly, partly due to the bad connection between the keel and bottom planking, and partly because the keel is too narrow. The keel and planking are fastened with only one row of brass screws which secure the bottom planking to the keel in the hulls of the F.3 type.

Another weak point is the discontinuity of transverse strength caused by running the timbers down to the keel and stopping them there, no provision really being made to hold the centre girder to the bottom planking or sides of the hull.

When the F.5 was designed, the keel was connected to the keelson by long "U" bolts which ran down the side of keelson and through the keel as in Fig. "A." In my opinion this design was so unsatisfactory that if it had been fitted to any boats they would not have been in commission very long before they leaked badly. This construction called for very careful workmanship, as only about $^{1}/_{32}$in. of wood was left between the side of keel and the bolt. Assuming the holes in keel had been bored very carefully and the bolt rammed home, which was securely fastened at the top of keelson by nuts in a small channel, as soon as the boat grounded, or was placed in a trolley, the thin strip of keel between bolt and side would have split, with the result water would have found its way up the side of bolt and into the bilges. Although this construction was so weak and did not lend to quick production, it was with great difficulty I was allowed to modify same to the usual simple boat practice of fastening the keelson to keel by brass screws.

In the F.5 type, the timbers are continuous from fin chine to fin chine forming a much stronger combination. The keel was increased in depth to $1^{13}/_{16}$ins., the width being kept the same, namely $2\frac{1}{2}$ins. It would have been much better if the siding had been increased instead of the moulded depth. The bottom planking is again only fastened with one row of brass screws, which is

insufficient. However, a great improvement was made by the continuous timbers as they were through-fastened to the keel by copper rivets.

Keelson.—The keelson is fastened to the keel in the F.3 boats by brass screws 18ins. apart, but in the F.5 boats the spacing is 9ins., and the screws are hove up through the bottom of the keel. Although the keelson in some parts measures nearly 12ins. in depth, it is greatly weakened by having one third of the depth cut out to accommodate the floors.

Floors.—The floors in the F.5 boats have been cut away two-thirds of the depth, thereby sacrificing strength to accommodate the keelson. A built-up floor would have been much more effective, and probably about 40 per cent. lighter.

Timbers.—The timbers are of American rock elm, $\frac{1}{2}$in. by $\frac{1}{2}$in., spaced 4ins. apart amidships increasing to 7ins. at the ends of the boat and terminate at the

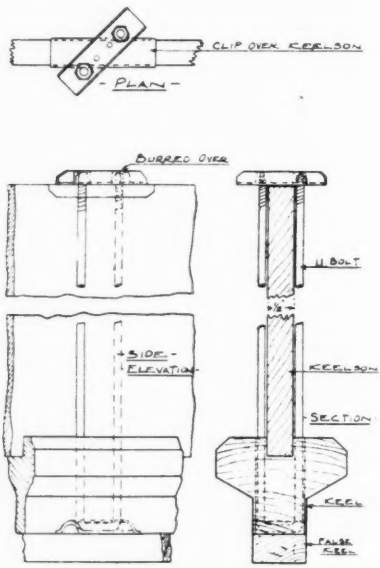


Fig. A.

lower chine; but it would have been an improvement had they been carried to the upper chine. The timbers are through-fastened to the keel by copper rivets.

Fin Top.—The timbers under the fin for the early F.3 hulls were heavy and widely spaced, but the later boat's timbers, $\frac{3}{4}$in. by $\frac{5}{16}$in., spaced 2ins. apart, were substituted to permit all through-fastenings of the diagonal planking on the hard wood timbers. It might also be stated here that the fin top of the first series of F. boats was three-ply birch, and in later types was covered with fabric and varnished. The introduction of diagonal planking was a great improvement on this system. All the fins on the F.3 class are flat, but on the F.5 type have $\frac{1}{2}$in. camber, which adds to the strength, gives a better appearance, and assists in getting rid of water easily.

Stringers.—Two stringers, equally spaced from the fin member, run under the fin, and other two stringers placed immediately below these on the bottom are connected by $\frac{1}{2}$in. square posts spaced 1ft. apart. Intermediate stringers,

16ft. long, are introduced in the fore part of the boat to further strengthen the shell and to absorb shocks when the hull alights on the water.

Fin Member.—In the first boats of the F. type the fin member was of American rock elm. On account of improper connection between the side of the hull and the fin top, the longitudinal seam naturally opened up, so in later hulls the fin member was constructed with the member and bead in one. This in turn might be improved by rabbeting out a piece at the back to allow the sides to house correctly.

Bow and Nose.—The timbers at the bow are of rock elm ¼in. by ⅜in., spaced 2½ins. apart, and are reinforced by horizontal stiffeners below the top longerons. These are spaced to take the outer seams of planking, tapered towards the stem and connected to the same by small oak breasthooks. These breasthooks bend the two sides of the bow together at the juncture of the stringer and stem, thus forming a very strong combination. Above the top longeron there are ten deck stringers which are notched to take the ribs, together with three strong beams which sub-divide the athwartship ribs. This skeleton, which is shaped like a dome, is planked diagonally, the inner skin being laid at 45 degrees with the forward ends of the planks lowermost. The outer skin is laid approximately fore and aft to suit the curve of nose. Each skin is of mahogany $^{3}/_{32}$in. thick, the planking being fastened to strong beams with wood screws. Where stringers and ribs occur, copper nails are driven through and fastened on grooves on the outer skin; elsewhere the planks are fastened with copper nails spaced about 1in. apart.

Sides.—Abaft the bow planking the sides are of three-ply birch and extend from the bottom of the fin member to the top longeron, running aft to the gun-port openings, a distance of about 18ft. The three-ply boards are butted against the side stanchions, thus saving butt straps. In the early F. types, the sides abaft the gun-port openings were built up of a narrow strip of mahogany, which formed a washstrake, with fabric stretched between same and upper longeron. The fabric proved not to be strong enough, so this system was superseded by $^{1}/_{16}$in. diagonal planking with nainsook between the skins. This planking was fastened to timbers running from longeron to longeron, spaced 2ins. apart, with one stringer midway running fore and aft. The new tail planking was a great improvement, although it added about 47lbs. to the weight of the hull; but experience has justified the change and extra cost. Several of the latest hulls have the sides covered with two-ply "consuta" made up of two pieces of very thin mahogany sewn together with flax thread, which is lighter than riveted work.

Bottom Planking.—This is arranged on the diagonal system, the inner skin being of cedar ⅛in. thick at the ends and $^{3}/_{16}$in. thick amidships, fitted at an angle of 45 degrees inclination to the keel. The outer skin is of mahogany $^{5}/_{32}$in. thick forward, $^{3}/_{16}$in. thick amidships, and ⅛in. thick aft, the planking being at an angle of 30 degrees with the forward end of the planks butting against the keel. This arrangement tends to diminish surface friction in wake of the seams. A layer of varnished fabric is fitted between the two skins making the structure very strong. The planking is fastened together with copper nails, and to the floors and stringers with brass screws. Along the keel and fin member it is connected with brass screws 1½ins. apart.

In the earlier types of boats, the planking was 5ins. in breadth with the rivets widely spaced, but it was found that with this breadth the atmosphere affected such thin material and opening of the seams resulted. The planking was afterwards cut down to 3½ins. in breadth. It was also found necessary to keep the rivets very close to the edge of the planks as there was a tendency for the planks to buckle. The bottom planking extends to the fin chine which runs from the bow for fully two-thirds of the length of the boat.

Top of Hull.—The transverse strength is made up of beams and arches combined with spruce stringers spaced about 7ins. apart. The deck aft is built and covered with fabric, and the stringers decreased to a minimum in order to keep the tail weight as low as possible.

Bulkheads.—These are four in number, each running from the top of the floors to a few inches above the top of the fin line. They are of $^1/_{16}$in. three-ply birch, stiffened by diagonal spruce stiffeners. The top of the bulkhead is stiffened by a capping piece of spruce. Where a bulkhead is in line with the floor, it is necessary to fit a packing piece between the floor and the bulkhead, except amidships, where the keel is practically horizontal.

Where elevator control wires pass through a bulkhead, a fabric stocking joint with brass washer plates on each side keep the bulkhead watertight, and where centre bracing struts pass through, a three-ply watertight collar is fitted.

Metal Fittings.—The chief elements of the structure, such as struts, pillars, beams, floors, wing root spars, etc., are held and bound together by light steel fittings of about 16 B.W.G.

The metal fittings were so numerous in the F. type that they had considerable influence on production, and I am of the opinion that they have been much overdone on these boats, while the opposite is the case on the N. boats. It would improve and cheapen the job considerably if a metal fitting were introduced at the ends of stringers and hatches, instead of the wood knees, which are not strong and take up much time to make and fit.

Bracing.—The longerons combined with the struts and stays form the principal superstructure of the hull above the fin top. From the nose to the gun port openings these vertical and diagonal struts are of spruce, moulded to give the greatest strength with lightest section. Abaft the gun-port opening to the stern-post the vertical and horizontal struts are 1in. mild steel tubes, braced diagonally fore and aft and transversely with 10 B.W.G. wire, all the wires being adjusted by turnbuckles. The tail of the hull is not too stiff in torsion, so adjustment with the bracing wires must be carefully carried out, and all the turnbuckles locked.

Wing Root Spars.—The wing root spars rank among the most important pieces of the structure. They are held in position at the sides and centre of the hull by heavy stanchions and struts. The centre bracing struts are slotted, let over the keelson to which they are bolted, the ends resting on the keel. This may not be considered good practice, as it compels concentration of thrust in a small area, resulting in some cases in springing of the bottom planking and fastenings. Until quite recently all wing root spars were of solid section, grade "A" silver spruce, but these are now laminated in two or three sections.

Outside the hull, and running fore and aft, six ribs of brasswood, all equally spaced from the longeron to the end of the spar, further strengthen and help to keep the spars in place. These ribs have two small stringers passing through them, giving firmness to the structure, which in turn is covered on top with three-ply birch, and on the bottom a fabric is stretched from the leading edge to the trailing edge, the whole forming the wing roots.

Interior of Hull.—The bottom deck is of sparred spruce boards, varying in width from 3ins. to 4ins., screwed to the top of the floors.

About amidships, where the petrol tanks are stored, the floors are shaped to take the tank stools and are specially stiffened and built up at the sides to form the tank cradles.

Steps.—The steps of the F.2a and F.3 boats are framed with ash bearers $\frac{1}{2}$in. thick, and are 3ins. deep at the after edge, tapering to meet a board which runs off to a feather edge forward.

The bearers are spaced about 5ins. apart, and though fastened to the bottom planking, where the timbers come in the way, they also take the fastenings. The bearers are joggled to take the step timbers, which are of ash $\frac{3}{8}$in. by $\frac{5}{16}$in., spaced about 2ins. apart. The inner skin of the planking is of $\frac{3}{16}$in. cedar, and the outer skin of mahogany of the same thickness, both laid diagonally. The whole step is constructed at the bench, fixed in place, and screwed on to the bearers.

At the forward edge of the steps a 6in. copper band of light gauge covers the edge of the step, the forward edge of which is sunk into the bottom planking.

Trouble was experienced with the feather boards swelling, and in some cases coming away altogether, due to the "tearing" or frictional resistance of the water when the hulls were driven at great speeds just previous to their getting off. This was remedied in the F.5 boats by carrying the outer skin of the bottom right through from end to end of the boat. The outer skin abaft the back step was then put on and carried forward to a feather edge under the back step, while a short false inner skin was fitted over the usual step framing and then attached to the

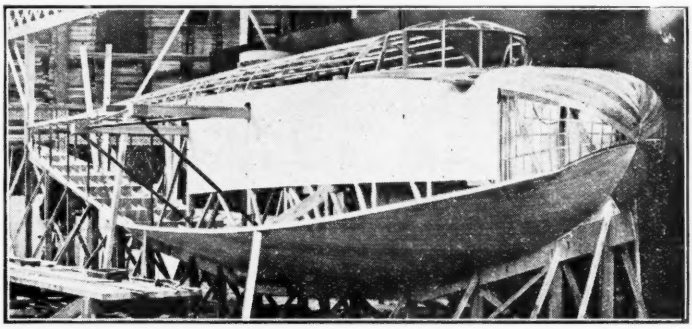


Photo No. 5.—View showing general construction of F3.

bottom skin. The outer skin between the steps was put on from the after end of the back step and worked forward to a feather edge under the main step with a false inner skin as before. The outer skin of the fore bottom was then carried right over this from the after side of the main step to the stem. This construction is much stronger and a great improvement on the former step.

Painting.—The inside, as far up as the fin top and the end of the tail, is coated with bitumastic paint, while the remaining portions are varnished.

Until recently the bottoms were varnished, and when the final coat was tacky, blacklead was rubbed in and the surface polished. This treatment is as applied on racing yachts, and has proved to be excellent, but as it involved a considerable amount of work at the stations, keeping the bottoms in good condition, it was superseded by black anti-fouling composition.

In some cases the anti-fouling composition has not proved very satisfactory, but as far as I am aware this is due to the builders not applying same properly. The paint should be stirred all the time it is being used, and again the boat should be put in the water before the anti-fouling is properly dry.

Another good protection to cover the bottom and fin tops would be velure paint, with a coating of varnish. This would be lighter than the blacklead and varnish, or the composition covering. The outside work not requiring paint is varnished, and should receive at least three good coats, occasionally being rubbed

down and revarnished. This is usually neglected with, of course, disastrous results to the material.

Two coats of black store enamel are applied to all the steel fittings. (See Photo No. 5, General Constructional View of F.3.)

TYPES "P." AND "N."

Generally the hull construction of the "P." and "N." types consists of a number of stringers disposed around the more or less circular section of the boat. Photo No. 5, General Constructional View of F.3.

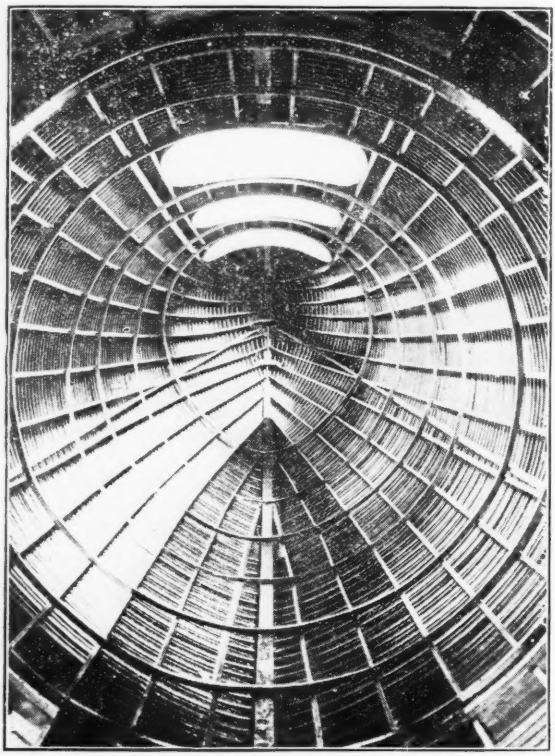


Photo No. 6.—The P5, showing circular section.

Stringers.—The longitudinal stringers are of spruce, 2¼ins., moulded at amidships, tapering to 1in. forward and ⅜in. aft, all sided $^{5}/_{16}$in. All the stringers have a pair of spruce fillets at the bottom and a pair of similar fillets at the top, all of which are glued and fastened through the floors and skin. I suggest that these stringers and fillets should be worked out of the solid, forming a lighter and stronger "I" girder.

The stringers are secured to interior bent wood hoops of rock elm spaced at intervals apart and extending in planes transversely to the longitudinal axis. The hoops are doubled in wake of the spars alternately scarfed at the top and bottom.

Timbers.—Externally, around the longitudinal stringers, are a number of bent wood ribs or timber of rock elm, moulded $\frac{5}{16}$in., sided $\frac{3}{8}$in. and spaced 2ins. apart, except at the bow, where they are fitted as cant timbers and spaced 2½ins. apart. All timbers are in one piece, bent right round the hull with the ends at the keel, into which they are joggled and glued to the stringers.

Floor Timbers.—The bent floor timbers are of rock elm, $\frac{5}{8}$in. moulded, sided $\frac{3}{8}$in. at the centre of the keel and tapered to $\frac{1}{4}$in. moulded and $\frac{3}{8}$in. sided at the ends, all of which embrace one-quarter of the hull, thus ensuring perfect transverse continuity of strength in the timbers.

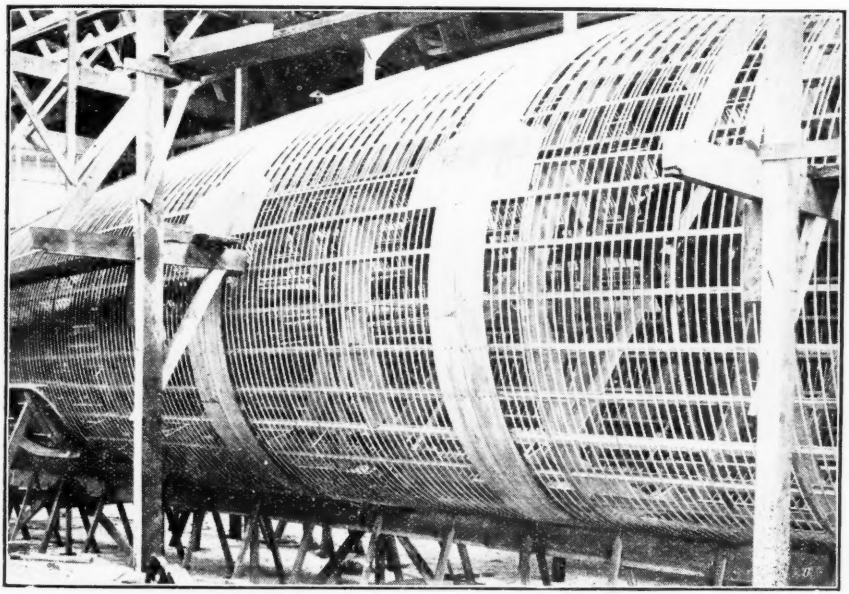


Photo No. 7.—The N4 Titania, showing timbers, stringers, and straps.

Keel.—The keel is of rock elm, moulded 1¾ins., sided 3ins. at amidships and tapered at the ends. It is in one piece and runs up to form the stem and is a great improvement on the construction adopted in the "F." type.

Keelson.—The keelson is of spruce, 5ins. moulded at amidships and tapered to stem on fore end and to 2ins. on after end. It is sided $\frac{5}{8}$in. parallel throughout. The bottom is carefully joggled over the floors and glued and secured to the keel by two spruce fillets, which are glued and through-fastened to the keelson, keel and floors. The top side of keelson is rabbeted into the underside of a top member or flange, which is secured by glue and screws. This top member or flange is of spruce, moulded $\frac{7}{8}$in. at centre and tapering to $\frac{3}{4}$in., sided 2½ins. at centre tapering to stem forward and to 1¼ins. aft; the keel, keelson and top member forms a very strong "I" girder.

Sternpost and Saddle Straps.—The sternpost is of mahogany, 3ins. moulded and sided, which extends to 1ft. above the hull. Saddle straps of elm are fitted, those at the main spars and tail-plane struts are in one piece, running round the boat with their ends fastened to the keel, as in the case of ordinary timbers, and of the same thickness. (See Photo No. 7 for Timbers, Stringers and Straps.)

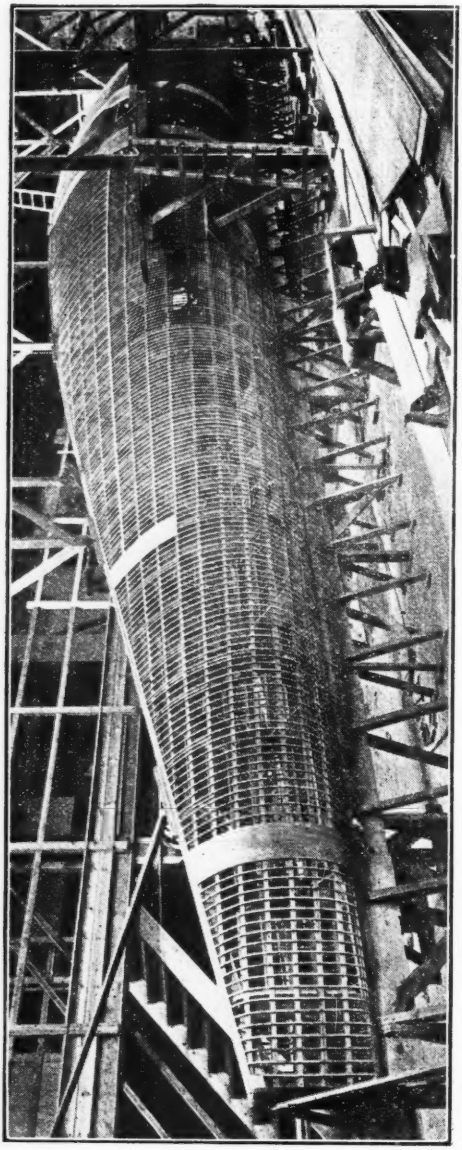


Photo No. 8.—N4. Complete hull in frame.

Doublers.—In addition, doublings of English elm are fitted at the wing root stay plates at front and rear spars. These doublings are carried in a fore and aft direction for a length of 30ins., carefully joggled over the timbers and floors. (See Photo No. 8, N.4 Complete Hull in Frame.)

Planking.—The planking is of Honduras mahogany fitted in narrow widths with close seams. The inner skin, $^{3}/_{32}$in. thick, being laid diagonally, the outer skin, $^{3}/_{16}$in. thick of the same material, is laid fore and aft. I am of the opinion this might be improved by fitting the diagonal planking 45° inside and 35° outside, and as the stringers run fore and aft, this would make a very strong job. The saving in labour would be considerable; roughly it might be stated if in the N.4 ten men took three weeks to do the outer skin fore and aft, eight men would do the same diagonally in two weeks. In the first case the wages bill would be, say, £150, and in the second £80, which shows a saving of nearly 50 per cent. One has only to consider the time spent in dividing out and in tapering and shaping the planks fore and aft to appreciate the above.

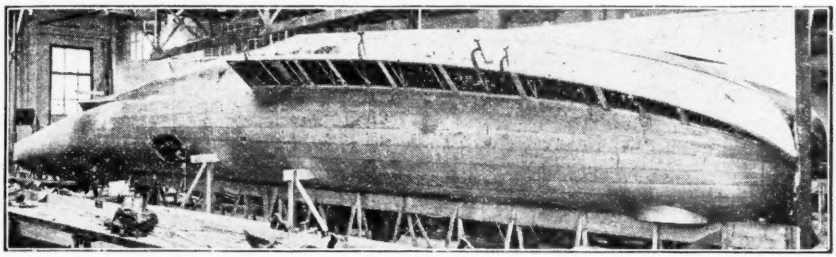


Photo No. 9.—P5, showing planking and steps.

Varnished nainsook is laid between these skins; this not only makes a watertight job, but is light and very strong. The inner diagonal skin is held in position with copper pins, the outer being through-fastened to the timbers with copper nails, the ends turned on the face of the timbers.

Steps.—Outside the main structure already described, a double bottom or water planing surface is fitted, known as the step. The water planes are framed up forward of the main step with three-ply birch and small stiffeners, the frames being spaced 18ins. apart and secured to the inner hull planing-bottom with spruce fillets.

The chine of rock elm is in one piece and tapered from 1½ins. by 1½ins. at the front step to 1¼ins. by 1in. at the stem. The stringers are of spruce all in one piece fore and aft, fitted through the three-ply frames, which are fixed to them by small fillets.

The timbers are of rock elm of the same size and spacing as in the main hull, the ends joggled into the chines and tapered to fit the hull. They are secured to the face of the stringers with glue and light copper pins. The bottom is planked with a double skin of mahogany with varnished nainsook between, similar to the main hull. (See Photo No. 9, P.5 showing Planking and Steps.)

Fin Top.—The fin top is framed with rock elm timbers spaced 2ins. apart, the ends being joggled into the chines and into a fillet of rock elm. The whole is planked in a similar manner to the inner hull, carefully fitted to the chine and hull-fillet rabbets and closely fastened with screws.

Protection Plates.—Rubbing plates of $^{1}/_{16}$in. brass, bent to the shape of the bottom, are fitted along the keel, and the chines are also protected by brass strips

fitted along the sides and bottom with the fore ends let in flush and secured by screws.

A strong point in favour of the small transverse framed hull is its resiliency, as it does not depend for its efficiency upon the rigidity of the parts comprising it. (See Photo No. 10, N.4 Interior View Looking Forward.)

Up to the present all flying boats have been built principally of wood, but Messrs. Beardmore have recently taken the next step towards advancement in building a composite boat. This is a stage in construction shipbuilders arrived at

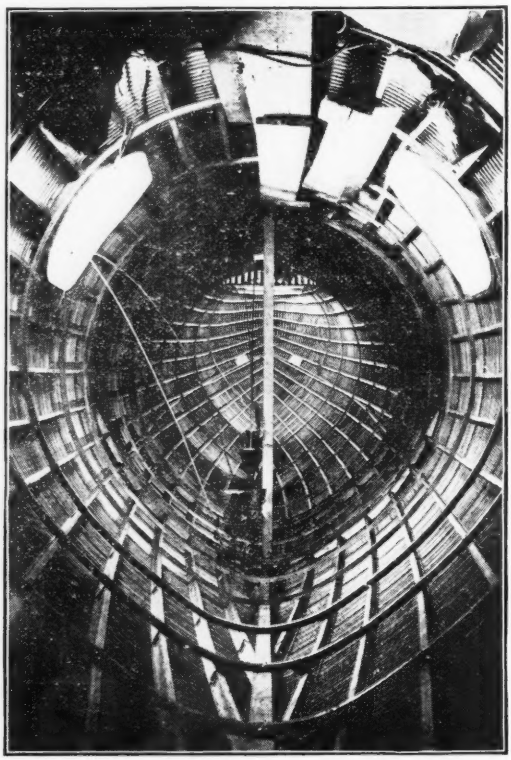
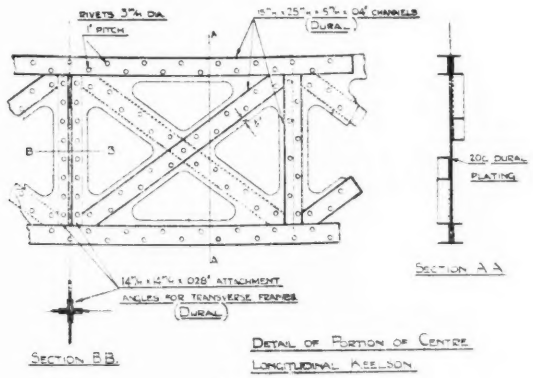


Photo No. 10.—The N4 Titania. Interior view looking forward.

many years ago, and at that time many problems had to be solved to get a satisfactory job. However, Naval Architects mastered all the problems, with the result many good composite boats are still in commission. The composite boat known as "W.B.IX.," built by Beardmore, is on the longitudinal system, the main portion of the hull being of approximately circular form. There are 17 continuous longitudinals, which run right fore and aft, care being taken that none of these members are cut throughout their entire length. The seven longitudinals on the lower side of the hull are built as shown in sketch 1, and the remaining longitudinals on the top side are built as shown in sketch 2. The channels forming these longitudinals are of duralumin 25mm. × 15mm. × 15mm. × .04ins. thick, and are braced as shown in sketches 1 and 2.

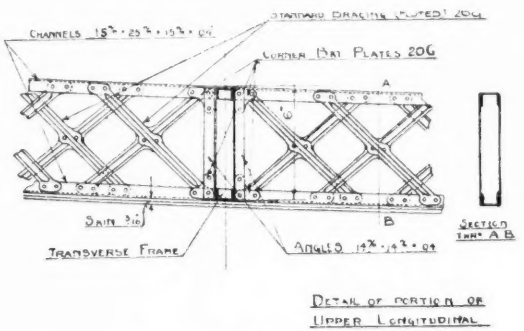
The main transverse frames are intercostal between the fore and aft longitudinals and are spaced along the boat at approximately 2ft. apart. (For construction see sketch 3.)

The channels forming the transverse frames are the same size as those in the longitudinals. The transverse frames are connected to the longitudinals by duralumin double angles 14mm. × 14mm. × .028ins. and gusset plates of .04ins. thick.



Sketch 1.

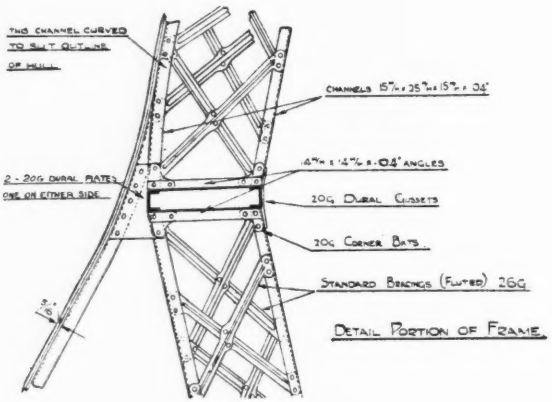
The framing from keel to chines and from chines to hull side is formed of duralumin channels 25mm. × 15mm. × 15mm. × .04ins., this framing being braced and supported to the main portion of the hull by duralumin channels and gusset plates.



Sketch 2.

Intermediate transverse framing is fitted from chine to keel and keel to chine on the bottom of the boat, the spacing of these transverse frames being approximately 8ins. Intermediate longitudinal frames are also fitted approximately 6ins. apart, the latter framework forming a support for the skin of boat. These intermediate transverse and longitudinal frames are formed of light duralumin channels .033ins. thick and .04ins. thick as required. The intermediate transverse and longitudinal framing on the top of the boat is of similar construction to that on the bottom, the framing at this part forming 8in. squares of the same section of channel.

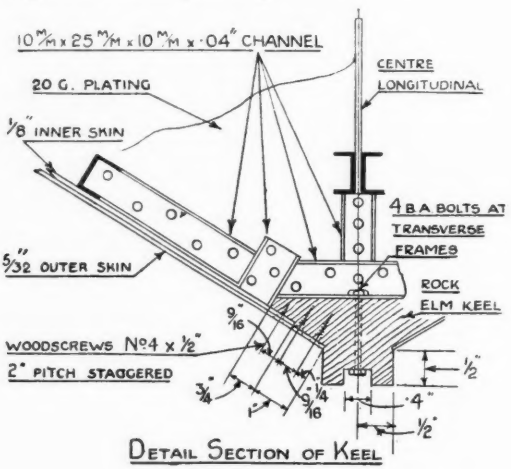
The continuous main longitudinals run right forward and finish into a heavy transverse nose frame built of duralumin channel and plate, thereby forming a very rigid structure forward. In front of this frame the nose of the boat is made of a removable steel nose cap which can be removed and replaced in the event of damage.


TWO CHANNEL CURVED TO SUIT OUTLINE OF HULL
CHANNELS 15"M x 25"M x 15"M x .04"
2 - 20G DURAL PLATES ONE ON EITHER SIDE
20G DURAL GUSSETS
20G CORNER BKTS.
STANDARD BRACKS (FLUTED) 20G
DETAIL PORTION OF FRAME.

Sketch 3.

The keel and chines are of American rock elm and are double rabbeted to take the two-ply skin. (See sketches 4 and 5.)

This double rabbet is a great improvement over the method adopted in the F. boats, but the chine piece would have been better if a greater distance had been left between the edge and end of planking.



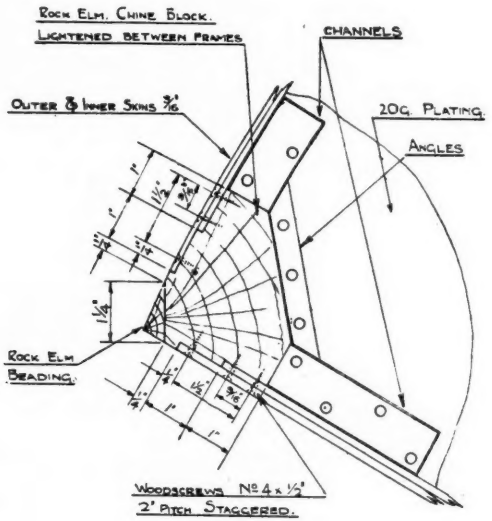
Sketch 4.

The skin below the chines is formed of two thicknesses of mahogany planking, the inner thickness being $\frac{1}{8}$in. laid at an angle of 45°, and the outer thickness $^{5}/_{32}$in. laid fore and aft. One ply of varnished cotton fabric is laid between the mahogany skins. The skin is fastened to the duralumin framing by $^{1}/_{16}$in. dura-

lumin nails clenched over rooves in the inside of the hull. The two skins clear of the framing are rivetted together with similar nails clenched over rooves. The skin above the chines is of two thicknesses, each $^{3}/_{32}$in. mahogany, the inner thickness laid at 45° and the outer thickness fore and aft, with varnished fabric between. Attachment to framing is similar to that of the bottom skin.

The builders have avoided many of the mistakes the early constructors made in the fastenings, as for instance in some of the F.3 boats there were only about 60 rivets per square foot; but I am of the opinion Beardmore have overdone the fastening, as they have about 160 rivets per square foot in the skin.

The framing-in way of the step is of wood and consists of eight $\frac{1}{2}$in. elm fore and aft formers and 23 $\frac{1}{2}$in. by $\frac{3}{8}$in. rock elm transverse formers each side of centre line with finishing transverse former at rear end of step $\frac{5}{8}$in. by $\frac{5}{8}$in.



Detail Section of Chine.

Sketch 5.

rock elm. The step is open to the sea, no attempt having been made meantime to provide watertightness.

Six 2$\frac{3}{4}$ins. diameter vent holes spaced 15ins. centres are provided on the bottom of the hull, just aft of the step, to ventilate same. These vent holes are led into a common pipe, one on each side, and led out from skin about 15ins. above the load water-line. Watertightness is provided where the vent pipes go through the hull bottom by rubber rings and dished washer plates, the end of the pipe being spun over on the outside.

The sternpost is of duralumin 2ins. by 1in. solid in section faced on each side by elm blocks, to make up the line of hull. From the sternpost forward 1ft. 10in., in the centre of the boat, duralumin plating is fitted from keel to top, reinforced with duralumin channels to provide for landing shocks in way of rear skid.

The engine-bearers are built of duralumin channels and plates and are placed on the main fore and aft bottom longitudinals to distribute the load over the hull.

There are three watertight bulkheads fitted in the length of the boat.

A hand-winding anchor gear is provided in the nose, the cable being led through the fore foot; the structure being suitably reinforced in the vicinity and a watertight cable guide provided.

In order to prevent corrosion, the whole of the duralumin framework is coated with oleo resin asphaltum varnish, this being done during construction in order that all joints are well protected. Inside the boat, in way of the engine room, there is an additional two coats of paint composed of graphite and tung oil varnish.

The whole structure is enormously strong, in fact too strong for the work it has to perform, with the result that the hull is much too heavy. The framework is so rigid that the boat could at any time be completely replanked without distortion to the shape of the general lines.

This boat has not yet been tested, but I am afraid the rigidity of the hull will prove to be one of the weak points in the design. The details and general workmanship are very good and show a great improvement on many of the service boats.

SUPERMARINE FOUR-SEATER.

The construction is such that the hull is capable of resilient distortion, so that when alighting on the water or when subject to other forces the hull can spring, thereby materially reducing the effect of the shock.

The cross section is egg-shaped, being very light and yet possesses great strength. The hull is built up of longitudinal stringers with bent hoop timbers inside and light frames outside the stringers with double planking outside the light frames, all these being through-fastened together.

The stringers are recessed to take the light frames, thus giving a good faying surface for the skin. The keelson constitutes a stringer, as it is of similar section.

One of the principal features of this design is that no web frames or cross-bracings are required. The hull is a continuous structure, so that the steps are built on to the skin planking. The top of step is connected to a longitudinal fin member, while the bottom is secured directly by small timbers to the hull. The fins are supported inside by thwartship cross members, small bulkheads and longitudinal members, to give the requisite strength for this member.

As many of the sections are of similar design and construction, this lends itself to quick production. All the stringers can be run out in the mill, also the timbers, thus a fair percentage of the work can be executed in running lengths, this being a great improvement on the construction of the " F." type, with so many different sections and details which require to be done by hand.

If these boats are being built in numbers, all the planking can be cut in pairs. The diagonal planking being parallel and of equal thickness, can, together with the stringers, timbers, etc., be made stock sizes and issued out in lengths from the store.

As a commercial and production proposition the following are the outstanding features:—

The reduction of raw material to mahogany, rock elm and spruce, brasswood, screws, copper nails and rooves, fabric, marine glue, black varnish and boat varnish, the first of which can be converted into $\frac{1}{8}$in. planking of convenient lengths and widths ($\frac{1}{4}$in. × $\frac{1}{4}$in., $\frac{3}{8}$in. × $\frac{3}{8}$in.), or $\frac{1}{2}$in. × $\frac{1}{2}$in. rock elm timbers into suitable lengths, stringers of spruce into suitable lengths, and be issued out on the job as required or in suitable quantities for the construction of each hull.

Take a hull of 35ft. in length, you can employ one class of labour only, for instance—boatbuilders; a small number of men and boys can be placed on this job, and if piece-worked, with the exception of supervision and inspection, the chances of hold-up through materials are so small, owing to there being no complication, that they can carry straight through and finish their job. Compare this, for example, with a flying boat of the F.3 or F.5 type. You have to start criticising this at the ordinary commercial proposition, in the first instance, of storekeeping. You run into such items as turnbuckles, bolts and nuts, wires, cables, sheet steel, steel tubing, in fact a hundred and one parts that go to the building of a large aeroplane's fuselage. You must employ not one trade but quite a number, such as boatbuilders, carpenters, sheet metal workers, fitters, machine hands, wiremen, riggers, and are immediately in the midst of demarcation troubles, allocations and arrangement of working squads, processing in a dozen different ways; your inspection costs go up in many details, all of which are liable to hold up the job—even a small point if turned down in inspection can completely stop the job for days on end—and if the question of finished stores is not a highly organised one, a small bolt and nut, wiring plate, etc., going adrift means a stoppage. Stoppage means money, and invariably these stoppages occur which, apart from their own cost, lower the moral of the particular men who are working for completion on the job. Without going into further detail, the foregoing, I think, points out the advantages and disadvantages of the two types from a construction point of view both from ease of construction, expense and on-costs.

During the recent year the Supermarine Company have patented a flexible bulkhead. Owing to the work of the hulls when in any kind of sea-way, it is impossible to make rigid fastenings to the hull, in fact if this is done the object of the flexible hull is at once destroyed, and if heavily strained the same experience is found in light racing launches, the hull, although not breaking at the bulkhead, throws itself out or splits several feet away either in a forward or aft direction. If it is therefore desirable to bulkhead a resilient hull, this must be of a flexible nature.

After considerable experiments had been carried out a suitable type was used with every success, its nature being of double diagonal planking in between and round the edges of which was fitted heavy canvas, marine glued and through-fastened. Where this is to be fastened to the hull an inside timber or hoop is laid round the stringers and through-fastened to the stringers; a padding piece is laid between the hoop stringer and the skin, also through-fastened, forming a complete register round the hull. The bulkhead, complete with canvas collar, is then laid in the hull, the canvas necking assuming a "Z" shape in section on either side of the bulkhead. The bulkhead is then secured by floating cross members which allow the whole of the bulkhead to float in any direction or the hull to move in any direction round the bulkhead to an extent of about 2ins. on any diameter.

The arrangement of experimenting tests were carried out in an ordinary barrel, by stand pipe and water pressure, being fitted between the sound end of the barrel and the bulkhead, the other end of the barrel being removed.

Another Supermarine feature is the question of the step. All hulls constructed and designed by the Supermarine Company have built on fore and aft steps of a watertight nature. Each step is divided into two complete halves on the port and starboard side of the main keel proper, and each half is again divided into four separate watertight compartments. On these boats the steps continue or protrude a considerable distance forward of the hull proper. This protruding portion of the lower step is divided up by a collision bulkhead forming a fore peak, which in case of ramming any floating object, carries away the forward part of the step which is always out of water, and the chances of damaging the hull proper or the flotation part of the step are practically nil. The rear steps are also

divided into watertight compartments, the main object being in case of the step being holed or severely damaged, the chances of failure are 8 to 1, and anyway the design allows for the steps to be filled with water and then not to endanger the buoyancy of the boat to any extent which would be dangerous.

A further point is in case of bad damage the main circular part of the hull is not scrapped. The boat can be put into dry dock and have a complete new step built on it, which is a matter of great importance, both in war-time and from a commercial point of view.

The following facts may be of interest:—

Supermarine standard four-seater hull, 31ft. in length, takes three men and two boys on an average 5½ weeks to build, working on a 47-hour week. This type of hull, however, can be manufactured, if it is a question of saving time, in considerably less periods; for example, for the aircraft for the Martlesham amphibian trials the Supermarine Company designed and completed a flying boat in all respects in 10 weeks from the time when the first drawing was commenced to the time the aircraft was in the air, the actual hull building time being 4½ weeks. This hull was considerably bigger than the standard type of Supermarine construction.

It is worthy to note that during the firm's trials at Southampton this aircraft landed in a ploughed field, with furrows of about 15in., which not only pulled the amphibian up in a very short distance, but owing to the heaviness of the ground, threw the boat forward on its nose, leaving the section of the hull on the earth for a distance of about 15 yards. The boat was dropped on its tail, which also speaks of the rigidity of tail construction, to put up with such treatment, and was flown off and landed on Eastleigh Aerodrome, no damage of any kind, with the exception of scratched varnish, was experienced, and later during the trials the aircraft was often tripped in this manner by the pilot for turning purposes. Battens had been fitted in the fore part of the boat as rubbing strakes.

It was also definitely proved that the fear now existent with land machines of turning over at the bow in landing on heavy ground is not to be experienced by amphibian machines, while dropping the aircraft from its right forward position to down, resting on its tail skid, can give some idea of the strength of the hull construction.

It is to be noted in this particular type of hull that the rudder post or skid post is not at the end of the ship, but about 5ft. forward from the sternpost, which proves that this kind of construction can take immense loadings on small bearing areas or surfaces.

These hulls have proved to be very strong, as I have seen a 13-stone man jump several times from the engine-bearers on to the top of the hull without damaging it in the slightest way. The torsional strength has also proved to be good, as the same man was swinging at the tip of a 16ft. span tail plane which only gave approximately 1¼ins. deflection.

The same boats have often been stalled from heights up to 30ft. without showing the slightest damage to the hull. The foregoing are only a few of the severe and trying tests the hulls have been subjected to, and throughout they have shown themselves to be wonderful. The main and outstanding feature of the Supermarine hull is not an aeroplane that will float but a seaworthy boat that will fly.

I believe the Specification Committee of the Air Ministry have prepared a glossary of technical terms for general aircraft, but as far as I am aware have not included the technical terms used on flying boat hull construction. It appears to me this deficiency should be remedied, as several of the aircraft constructors have often asked me to define many of the Naval Architects' terms. I have endeavoured to fill this want, so have added as an appendix to this Paper the

general shipbuilders' terms as applied to flying boat hulls. I am aware the list is by no means comprehensive, so hope the members of this Society will ask for the terms they wish defined, or assist me in making the list complete.

APPENDIX "A."

GLOSSARY OF TERMS USED IN FLYING BOAT HULL CONSTRUCTION.

Afterbody.	The part of a boat abaft the midship section.
Alleyway.	Fore and aft passage under deck, or hood.
Amidships.	The centre fore and aft line of a boat.
Apron.	A piece of timber fitted to aft side of stem to form backing for plank ends.
Athwart.	Transversely, at right angles to fore and aft.
Base Line.	In N.A. a level line near the keel, from which all heights are measured perpendicular to it, sometimes called datum line.
Beam.	The transverse member to support the deck, and tie sides. The breadth of a boat.
Beam and Length.	The proportion of a boat's beam bears to her length varies according to her type.
Bilge.	The round in a boat's timbers or frames where they begin to approach a vertical direction.
Bilge Keelsons.	Stout pieces of timber or metal sections fitted inside a boat in a fore and aft direction along the bilge to strengthen her longitudinally.
Bilge Strakes.	Planks or plates worked longitudinally forming outer skin along the bilge, or over the heads and heels of the frames.
Bilge Water.	The water inside a boat, which lies in the bottom.
Blisters.	Unsightly bladders on paint are generally caused by putting new paint upon the top of old, or using very thick paint.
Boat Chocks.	Wood members cut to shape of thwartship section of boat where fitted.
Body.	Part of a boat's hull, as fore-body, middle-body and after-body.
Body Plan.	The plan which contains the cross sections of a boat's lines.
Bottom.	Usually understood as the part of a boat below the water line.
Box Scarf.	A method of joining two pieces of timber by letting each into the other one-half its own thickness.
Bulkheads.	The athwartship partitions which separate a boat into compartments, etc. Fore and after partitions are also termed bulkheads.
Bulwark.	The side of a boat above the deck.
Butt.	The joining or meeting of two pieces of wood endways. Butt and butt means that two planks meet end to end, but do not overlap.
Buttock Lines.	Planes in a fore and aft direction, showing the outline of vertical fore and aft sections.

Boot Top.	The portion of the surface coated with anti-fouling composition above the water level.
Battens.	Temporary fore and aft members around which the timbers are bent.
Bollard.	A vertical post, or fitting forming posts, in wood or metal for making fast cable, etc.
Breasthook.	A strong wood or metal knee fitted horizontally to stem.
Buttstraps.	A wood or metal doubling for connecting end of planks, or strakes of plating.
Cambered.	When the keel, deck, or fin top has its ends lower than its centre.
Cant Frames.	The frames in the bow and quarter of a boat that are not square to the keel.
Carlines.	Members fitted in way of deck openings, *i.e.*, half beams.
Carvel Built.	Built with the plank flush edge to edge.
Chine.	Where the top sides meet the bottom at an angle.
Clamps or Cramps.	A type of wedge vice, used in boat building to hold the planks together. Various contrivances of wood or metal used in fitting up a boat or in fixing parts in her construction.
To Clench.	To beat the end of a rivet until it forms a head, or to turn the end of a nail in so that it will not draw.
Cockpit.	A form of well in the deck.
Copper Fastened.	Fastened with copper nails or rooves and nails.
Caulking.	Driving cotton or other stopping into the seams, or in metal, clenching over edges to make watertight.
Ceiling.	The inside lining.
Coamings.	A raised frame fitted to and above the deck for hatches, or other openings.
Chain Girth.	The shortest distance measured round the hull from gunwale to gunwale.
Chain Plates.	A metal fitting rigidly attached to the hull to take shrouds.
Collars W. T.	Metal, wood, or other fitting round stringers, etc., where they pass through bulkheads or decks to make same W.T.
Composite.	The form of hull in which metal and wood construction are jointly used.
"D."	The capital letter "D" is used by naval architects to denote the displacement or total weight of the boat and her equipment, generally expressed in pounds or tons.
Dead Wood.	The solid wood worked on top of the keel forward and aft.
Deck.	The platforms supported on the beams.
Doubler.	To put one thickness of plank or plate over the other.
Dowel.	A hard wood or metal pin used for connecting timber on the edges of planks.
Dump.	A nail used in fastening plank to the timbers, as distinguished from a through bolt.

Draught or Draft.	The distance between the lowest portion of the boat and the L.W.L.
Diagonal Ties.	Strengthening members, which are fitted at an angle to the stringers or beams.
Entrance.	The fore part of a boat, the bow. A good entrance into the water means a long well formed bow.
Fairing.	A process by which the inter-sections of curved lines with other lines in the body plan, half breadth plan, and sheer plan are made to correspond.
Fairleads.	Holes in plank fittings or metal for ropes or wires to lead through, so that they run fairly and are not nipped or formed into a bight.
False Keel.	A piece of timber or metal fitted under the main keel to deepen it.
Fastenings.	The bolts, nails, etc., by which the framing and planking are held together.
Fay, to.	To join pieces of timber together very closely. Plank is said to fay the timbers when it fits closely to it.
Feather Edge.	When a plank or timber tapers to a very thin edge, "Tapering to nothing."
Fender.	A buffer made of rope, wood, matting, cork, or other material to hang over the side of boat when she is about to come into contact with another boat or object.
Floors.	Transverse members connecting the heels of frames to bottom and keel.
Flush Deck.	When the deck has no raised or sunken part.
Fore body.	The fore part of a boat which is forward of the midship section.
Frames.	The transverse members to which the skin is fastened.
Freeboard.	The distance from W.L. to gunwale.
Flare.	When the breadth at the gunwale exceeds the breadth at L.W.L.
Fillet.	A packing or distance piece.
Filling.	A stopping for seams, etc.
Flat-Floored.	When the timbers and floors project from keel in a more or less horizontal direction.
Fore Foot.	The foremost part of the keel at its inter-section with the stem.
Foot Rails.	Fore and afters of hard wood or metal fitted to deck to give foothold.
Floor Boards.	A light decking inside the hull.
Fore Peak.	A compartment next the stem.
Futtocks.	The timbers which abut above the floors.
Garboard.	The strake of plank, or plates, next above the keel into which it is rabbeted and bolted, or riveted.
Grummet.	A ring formed of a single strand of rope laid over three times.
Gussets.	A connecting piece.
Gunwale.	The fore and after at the extreme breadth under deck.
Gratings.	Open wood work on bottom for decking.
Gripe.	The fore part of the dead wood.

Gudgeons.	Metal eyebolts fitted to the stern post to receive the pintles of the rudder.
Half-Breadth Plan.	A drawing showing the horizontal sections or water lines of a boat by halves.
Hanging Knee.	Knees that help to keep the beams and frame together, one arm is fastened to the under side of a beam, the other to the frame.
Harpings.	Pieces of timber or battens that are fitted around the frames in an unbroken line to keep the frames in their places before the planks or plates are put on.
Hatches or Hatchways.	Openings in the deck.
Hatchway Coamings.	The raised frame above the deck upon which the hatches or hatch covers rest.
Heel.	The lower aft end of anything as heel of the frame.
Hogged.	The form of a boat when she has combered sheer.
Hogg Piece.	A piece of timber worked upon top of keel to prevent its hogging or rising in the middle.
Hull.	The boat as distinct from her superstructure.
Half Beams.	Beams that are cut to take openings.
Hawsepipe.	A pipe fitted through the top sides to form a fairlead for mooring rope.
Hold.	Space for stowing cargo.
Hollow Lines.	The horizontal lines that have deflections.
Intercostal.	Fore and afters fitted against the stem which are cut at the floors.
Joggle.	A notch or notches forming a box scarf to enable two pieces of wood, etc., to fit together. In metal boats where the one plate, or metal, overlaps the other, giving an inside fair surface.
Keel.	The fore and aft members in a boat to which the frames and garboard strake are fastened, or if a diagonal planked boat, where the planks end.
Keelson.	An inside keel fitted over the throats of the floors.
Knees.	Pieces of timber or iron shaped to strengthen particular parts of a boat. A hanging knee is the one fitted under the beams; a lodging knee is a knee fitted horizontally to the beams and shelf or deck beams. Floor knees are V-shaped like breast hooks.
King Plank.	Centre plank of deck.
Lines.	A general term applied to the drawing or design of a boat as depicted by fore and aft lines and cross sections. A boat is said to have "fine lines" when she has a low block coefficient.
Load Water Line.	The line of flotation when a boat is properly laden or ballasted.
Lap.	The edge of one plank over the edge of another.
Locker.	A receptacle built into the boat.
Limber.	A waterway.
Moulded.	The thwartship dimension of timber or frames.
Moulded Breadth.	The greatest breadth of a boat without the plank.

Moulds.	The skeleton templates to cut the frames by, or to hold the boat in shape while the timbers and stringers are being fitted in place.
Manhole.	A circular scuttle, the minimum diameter through which a man can pass.
Mould Loft.	A building in which the floor is painted dull black, and is used for laying off lines full size.
Midships.	The centre of fore and aft lengths.
Mast Step.	The chock in which the wireless mast is housed.
Mortise.	A cut groove at a joint to take tenon.
Overhang.	The ends of a boat, which at the gunwale extend over the water, *i.e.*, L.O.A. exceeds L.W.L.
Overheads.	Beams, moulding, etc., forming ceiling under deck.
Parcel.	To cover a rope with strips of canvas painted or otherwise. The canvas is wound round the rope and stitched or "served" with marline.
Pintles.	The metal hooks by which rudders are attached to gudgeon sockets.
Planking.	The outside skin of a boat; plank laid on the frames or beams of a boat whether inside or outside.
Plank Sheer.	The outside plank at the deck edge which reaches the timber or frame heads, and shows the sheer of the boat.
Port.	The left hand side of the boat looking forward.
Partners.	A doubling between beams to take deck fittings.
Pillar.	Vertical supporting members under deck.
Quarter.	Top sides between full abeam and aft centre line.
Rabbet.	An angular channel or groove cut in the keel, stem or sternpost, etc., to receive the edges or ends of the plank.
Ribands.	Long pieces of plank or timber, sometimes called harpings, secured to the frames of a boat in a fore and aft direction, when she is building, and representing the dividing lines or geodetic lines.
Ribs.	The frames or timbers of a boat.
Rake.	At an angle to the vertical in a F. and A direction.
Risings.	A fore and aft by which seats or other items are supported.
Rail.	The extreme F. and A. top line above water.
Scantlings.	The dimensions of all material used in the construction of a boat.
Scarph or Scarf.	A method of joining pieces of wood or metal by tapering their ends. A box scarph is when the ends are not tapered, but a half thickness cut out of each part so that when put together the parts form only one thickness.
Seam.	The line formed by the meeting of two planks or plates.
Shift of Butts.	The fore and aft distance between the ends of one line of plank or plate and that of the next below or above.
Side Keelsons.	Stiffeners fitted fore and aft on either side of the keel.
Skin.	The outside or inside planking of a boat.
Starboard.	The right hand side of the boat looking forward.

Stem.	The forward vertical continuation of the keel.
Step.	A planing surface built in or on the bottom of hull.
Stringer.	Strengthening fore and afters connected to frames or timbers.
Scantling Section.	A drawing of mid-section of a boat on which all scantlings of same are stated.
Scupper.	A freeing port.
Sole Beams.	Thwartship beams, supporting flooring.
Strake.	A fore and aft line of plank, or plating.
Sheer Strake.	The top line of planking or plating.
Sheer.	Fore and aft curve of gunwale.
Shelf.	A fore and aft member round deck inside planking to which timbers and beams are attached.
Sheathing.	Metal or wood skin fitted outside planking for additional protection.
Skin Girth.	The distance measured round planking from gunwale to gunwale.
Scuttle.	An opening which can be made W.T.
Stopping.	A substance used for making seams W.T. when not caulked.
Sternpost.	The vertical member where the planking terminates aft.
Siding or Sided.	The fore and aft dimensions of timbers, beams, etc.
Stopwater.	A soft wood dowel driven through dead wood at joint of same.
Spiling.	A method of setting out a curve from a straight line.
Through Bolt.	Through fastening. Fastening that ties several thicknesses of material.
Timbers.	The transverse ribs of a boat.
Transom.	The frame at the sternpost of a boat. The transverse board at the stern, which gives shape to the quarters and forms the aft end of the boat.
Transverse.	Athwartships. At right angles to the line of keel.
Tie.	Diagonal connecting and strengthening member.
Tumblehome	Where the extreme breadth exceeds the breadth at deck.
Topsides.	The upper part of hull above W.L. excluding stem and stern.
Turtledeck.	A deck with excessive camber.
Trim.	The fore and aft inclination of hull about L.W.L.
Thwart.	A seat forming tie across the hull in the absence of beams.
Tenon.	A tongue at the end of a timber to fit into a mortise.
Throat.	The distance across the flat of a knee.
Timber Heads.	The upper ends of the frames.
Tuck.	Where hollow occurs in the form of the stern or quarters.
Ways.	Baulks of timber on which the cradle slides.
Well.	A sunken part of the deck usually termed cockpit.
Waterways.	Apertures to allow water to flow to bilge suction.
Waterplane.	The horizontal area of hull at water line.

DISCUSSION.

Wing Commander T. R. CAVE-BROWNE-CAVE said he felt singularly unfitted to open the discussion as he had only come to obtain information and could only speak on very general lines. He was sorry Capt. Nicolson did not speak more on the question of design, but he had given so much information on construction that it was obvious the design side had to be left out. Were the bulkheads the Lecturer advocated effective with the high load pressures one got when a boat was moving rapidly over the surface of the water or were they simply strong enough to be effective when it was at rest? On what tests were the merits of the various types of construction judged? With ordinary aeroplane construction different types could be tested by sand loading. He did not know whether sand loading for flying boats was sound, but if so he would be interested to know how the types of construction which had been compared came out under tests. It seemed to him difficult in dealing with flying boat problems to know exactly in what respect one construction was better than another. The man who departed from accepted naval architects' practice was going to have great difficulty in making his case unless there was a definite test to which he could appeal. If, for instance, a sand-loading test were recognised as being a good one, the two methods of construction could be practically compared. If there were no direct test one was inclined to be prejudiced in favour of the accepted construction which had been built up as the result of long practice. Capt. Nicolson threw no light upon the effect of size. All those who had thought seriously of the future of aircraft must realise that the very big machine was going to be a boat or amphibian, and consequently they wished to know what kind of problems became more and more difficult as the size increased. If one went to a really large boat, would the Author's view as to the best construction be modified?

Captain W. H. SAYERS said he knew very little about flying-boat work, but he knew one or two things about the history of the flying boats. No doubt Capt. Nicolson was right in his criticism of the design of those hulls, as boats, but after all they were parts of a flying machine, and they were constructed by people who were not naval architects, and who received no encouragement from naval architects, and who set out to make something fly. They made it fly, and laid the foundations of the flying boat industry. They deserved a great tribute of praise for fighting through the enormous difficulties they had to face and making something which, after all, floated on the water and flew in the air. It was some time after the flying boat had flown before any naval architect attacked the design of flying boat hulls and made one which flew, with the exception of the Sopwith Bat boat, and that was an entirely different proposition to the flying boat of the present day.

Mr. W. O. MANNING expressed his appreciation of the Lecture. The criticism of the different points of flying boat construction by a trained naval architect was one of the most useful things that could be brought before the flying boat industry. He thought that there was no doubt that the ordinary straightforward principles of boat building must be adopted in flying-boat work. All experience up to the present showed that the resilient type of boat was the best, and this introduced problems in the construction of the complete machine which did not exist in the case of a land machine. The hull panted very considerably on the trolley or in the water, often to the extent of 1in. or 1½ins., and one was faced with the problem of joining a comparatively rigid structure, viz., the main plane to a flexible structure, and to do this in a fairly rigid manner while permitting the hull to retain its flexibility. The problem had not been satisfactorily solved yet. The part of the hull that should be allowed to pant was that which took the greatest shock—the part which came under the main planes. In the usual type of boat that pant was stiffened up with the plane

structure and the wing root stays, and the result was that landing forces caused considerable stresses on the structure itself. Other problems also came in. The pilots' seats should not be attached rigidly; and very great care should be taken with the petrol connections. He had no doubt, however, that the problem would be satisfactorily solved. The question of bulkheads was important. There must be watertight bulkheads and compartments in boats of this type, but whether a bulkhead had been produced that would stand the shock of water coming in had not yet been proved. He did not know whether, if the space behind the bulkhead were filled up with bags containing air, it might be sufficient to make it stand up. The greatest shock the flying-boat industry had had was the death of Major Linton Hope. He was the originator of the circular type of hull and the basket type of construction applied to flying boats, and his pioneer work in these directions was of invaluable service to the industry.

Mr. GIBSON KNIGHT said the Author suggested that a committee of naval architects should draw up rules of construction and scantlings. That might ultimately be called for, but the time was hardly ripe for it. Its effect would be to cramp the designer's hand at a time when it should be as free as possible in order that the designing possibilities might be explored in all directions. It was quite advisable that the committee should consist of naval architects, but aircraft designers should be included. With regard to the division of the various types in the Paper, the "Supermarine" was set apart. Why was that done? In general, though perhaps not in points of detail construction, that type fell within the same class as the N.4 and P.5 types of flying boats.

Commander E. S. LAND (United States Navy) congratulated Captain Nicolson on the excellence of the Paper; also on his bravery in attacking the problem and attacking the people who had previously attacked it. At first blush his criticism might be considered iconoclastic, but on close analysis it is seen to be clearly constructive and should be welcomed, not only here, but also on the other side and wherever flying-boat construction is under way. With regard to the rules proposal, he (Commander Land) saw no reason why rules should not be laid down. Such rules are applied to boats, yachts and ships; why not to flying boats? He would like to second that suggestion.

The bulkheads are a serious and difficult problem to solve. They add much to the strength of that boat and should be installed. Whether the problem could be solved with the expansion joint, as suggested, without too much weight, he doubted. Putting an expansion joint in a flying boat, where watertight integrity is essential, is a complicated proposition. It might be done with the corrugated or pilaster bulkhead which was sometimes used for expansion purposes.

The Author's notes on the scrieve board they ought to take home and ponder. To do the laying-off properly in the beginning saved time and money and made for efficiency. They had been in this naval architect business since Noah or Jonah, and the mistakes made in this country were also made *ad lib.* on the other side by some people who did not take advantage of the knowledge they had before them. Possibly the pressure of the war was the cause of it. They might take a leaf out of the books of the designers of larger ships. He saw a close analogy between many types of flying boats and submarine and destroyer construction, especially when it came to obtaining proper strength. If one wanted strength and rigidity with resiliency, the latest designs of destroyers should be carefully studied. More strength in the side stringers and deck stringers might have solved some of the difficulties. The Isherwood system, which had been designed here, threw much light on the question of longitudinal versus transverse construction. In America they followed the transverse system until the Isherwood system was tried out, and it was surprising how quickly it was adopted, and how many thousands of tons of shipping were constructed on that principle.

He favoured the longitudinal construction, but most successful types of boat and ship design were compromises. He saw the advantage of the combination of longitudinal with transverse, as in the Isherwood sysem, and there was room for investigation along that line. When he looked at some early flying boats he sometimes wondered whether they had tried to design a spring hat of the latest Paris style or an Old Mother Hubbard shoe house.

In Great Britain and France one found relics decorating golf fields and pastures of some of those early designs. Their ideas of boat construction were not correct at that time, but some of the modern boats indicate that they were getting back to normal and to an appreciation of similarities to the designs of surface craft. The question of size, raised by Commander Cave, was important, because there was a great future for the larger types of boats of this kind.

He regretted that the Author did not say something about all-metal construction. There were a number of types in existence of metal construction, and they were fine looking specimens of work, but how successful they were in trials he could not say. He saw a great future in all-metal construction, both duralumin and strip steel, in which, as far as he was aware, Great Britain led at the present time. He hoped the Author would give his opinion about metal construction when he replied to the discussion.

Mr. SCOTT-PAINE said he had been building circular-constructed flying boats since about 1910, and was beginning to realise how little he knew about it. The difficulties in some instances were extraordinary. It was found many years ago when building light motor-boat hulls with bulkheads that an extraordinary distortion took place in heavy sea-ways, the planking, when breaking, always throwing out forward or abaft bulkheads, while similar hulls without bulkheads seemingly gave no trouble. Some of the racing rules demanded a bulkhead should be fitted, and one of the greatest difficulties was the fact that they had to be made rigidly fast to the sides and the bottom of the hull. In one experience, when running in a heavy sea, some of the planking blew about 6ft. abaft the forward bulkhead; the craft sank and was lost.

It was then tried to get flexible bulkheads, not only on account of the panting of the sides, but of the torsional disturbance of the hull and the coming up or panting of the bottom towards the deck. These were not successful.

The Air Ministry's decision at the recent Martlesham trials that three bulkheads must be fitted to amphibian machines was a great difficulty, it adding much extra weight, the hulls having to be built to stand severe strains in the event of a compartment flooding. This necessary strengthening of hulls was not referred to in the lecture. It might be thought of interest to describe the method of testing trial bulkheads.

An ordinary barrel was taken with one end out, the bulkheads being erected in the middle of the barrel, and by means of a 4in. stand pipe with a 20ft. head, 60 gallons of water were released, which blew the trial bulkheads every time. The difficulty was, however, successfully got over, and stood this pressure on several occasions. The bulkheads weighed about 20lbs. each.

Corrugations suggested by Commander Land would be impossible, as it only gave elasticity in one direction, and would not free the hull from torsional movement.

He was sorry the Lecturer had not said more about the construction and position of steps of hulls, the difficulty being to judge where to place the forward and aft steps to avoid porpoising

Mr. Scott-Paine said he was concerned in the building of a circular hull in 1910. Owing to the available engines, it did not fly. He thought the object

was not to try to make an aeroplane float, but to build a seaworthy hull that would fly.

The CHAIRMAN said he would quote actual facts relevant to Commander Cave's remarks about size. He (Major Low) had launched a theory that there were limits to the possible size of every machine, based on the materials available and on the skill of the designers, and that theory had not been perfectly understood by some critics. For instance, they found Commander Hunsaker, whose very name commanded their respect, saying this theory of geometrical similarity prescribed what would be very bad engineering. Commander Hunsaker said, "Fortunately one need not be discouraged by such theoretical considerations, as one had learnt from past experience that the weight of wings could be kept down nearly in direct proportion to their area. . . . That this result (continued Commander Hunsaker) was quite at variance with the theoretical deductions of several learned writers was illustrated by a table which gave the H.S. flying boat as about three tons, and the N.C. as about 12 tons. The theory of similarity showed as a first approximation that if one went from three tons to 12 tons, which was four times, the obvious way to do it was to cut one's factor of safety in half. That would give half the constructional coefficient, and according to the theory of geometrical similarity, which was admittedly a first approximation, the factor of safety was halved and the total weight multiplied by four." Having produced this table to kill the theorist and prove there was no limit, Commander Hunsaker (on page 732 of the "Journal of the Franklin Institute") said: "A point of interest not brought out in the table is that the structural factor of safety has fallen from six in the H.S. type weighing three tons to three in the N.C. type weighing 12 tons." He had in fact started out to curse the learned theorists, but by his table he confirmed his (Major Low's) firm belief that there were definite and close limits to the size of flying boats. He would be glad, without any consulting fee, to consult with any technical member of any designing firm not only in the application of this first approximation theory of geometrical similarity, but in the further approximation made possible by finer design on larger machines, and he thought it would save a great deal of money if it prevented people from launching out into 20 and 40 tonners and transatlantic liners which were going to carry hundreds of people. He believed he would save the industry and capitalists many hundreds of thousands of pounds if they consulted him first on this theory of the limitation of sizes. If only the hull had to be considered there would be no apparent limit in sight. It was the increasing weight of the wings which controlled the size.

The Chairman went on to approve warmly of the principle of handing over specialist parts of design to specialists, and in particular of consulting the yacht builder and naval architect when it came to the construction of hulls.

On his own behalf he thanked the lecturer warmly for one of the most satisfying papers he had listened to before this Society.

REPLY.

It will be noted that every speaker has dealt with the topic of bulkheads; this interest proves the truth of what I had stated—that a committee should be formed to look into the very important question of W.T. sub-division and methods of construction. I am convinced that if two or three naval architects are on such a committee, the bulkheads that are desirable will be obtained. It will be noted that shipbuilders realise the importance of this question, as at a recent meeting of the Institution of Naval Architects two papers were read on the same subject for larger boats. Shipbuilders have now got the effective bulkheads they require, as they have the experience of over 100 years of boat building

to go by, and yet we see aircraft builders starting off in a new direction when most of their difficulties have been solved by naval architects many years ago.

Wing-Commander Cave-Browne-Cave would like to have heard more on the subject of design, but I am sure he realises that it is not possible to treat both subjects at length in one paper. I might refer him to a paper I read before the Institution of Engineers and Shipbuilders in Scotland, in April, 1919, where he will find the design of flying boats dealt with more fully.

He also asks if the bulkheads I advocate would stand the inrush of water if the boat was going at a great speed on the surface of the water? There are very few cases when boats' bulkheads would be called upon to withstand such a pressure, but if the collision bulkhead was built in the form of a $<$ it should stand up as well as the original bow.

Sand loading tests have not been carried out to any extent on flying boats.

The late Major Linton Hope gave an example of a sand loading test on the A.D. boat in his paper before this Society, and later the N.4 Atlanta hull was tested for flexibility and bending, but the N.4 hull built on the longitudinal system has not yet been tested, so no comparison of the various types of hulls has yet been made, as the "A.D." and "Atlanta" are built on similar lines. However, sand loading tests are of very little value in determining if a boat's hull will give the required amount of flexibility and be seaworthy to stand the abuse they get by the sea.

Commander Cave-Browne-Cave states that the man who departs from accepted naval architects' practice is going to have difficulty in making his case; this is exactly what I have been trying to point out all along, but it does not seem to appeal to many aircraft designers and builders.

In yacht and boat building the test of weather and trials have proved to shipbuilders the types of construction which are best, but this depends of course on the duty and function the boat has to perform.

Naval architects design and build a boat in accordance with the kind of cargo she has to carry, or the climatic conditions under which she is to operate, or any other special trade which she may be called upon to run. The same applies to flying boat hulls. If a naval architect is told the duties the boat has to perform it will then be easy for him to decide on what type of construction should be adopted. With reference to the question on size of hulls I do not think this will trouble the shipbuilders for very many years to come, as we have had so much experience in large boat building. I have designed and built boats weighing as many tons as the largest present flying boats weigh in lbs.

If flying boats increase above, say, 80ft. in length, or over 30,000lbs. in weight, then metal construction could be profitably used.

Mr. Manning mentions panting of hulls, and this, as he states, is one of the vital points to be noted when designing a hull. The position and amount of panting cannot be calculated, therefore it is only by years of experience and by hundreds of tests that this factor can be obtained. As this has been the work of naval architects in the past I cannot now understand why they should not be consulted on the subject.

I am glad to note that Commander E. S. Land, of the U.S. Navy, seconds my suggestion that flying boats should be built under classification rules.

Commander Land, being a practical man, knows the importance of the scrieve board, and I hope his advice will be taken.

It may be interesting to the designers in this country to note that throughout Commander Land's remarks it can be seen that the Americans understand the

close analogy between flying boat construction and other types of shipbuilding and that on the other side naval architects are engaged on flying boats.

With reference to metal construction, as I have already stated, it certainly should be used when we come to the dimensions named in my reply to Commander Cave-Browne-Cave.

I have had a good deal of experience with steel boats and found that the material was not very suitable for light high-powered boats under 50ft. in length.

The chief disadvantages were the difficulty of obtaining a fair surface, which is of great importance in this type of boat, and secondly, the difficulty of making satisfactory joints in the material which was employed; but as the boats increased in size the difficulties disappeared and the metal construction became easier than wood.

With reference to Mr. Scott-Paine's remarks on the position of the steps, this is a question of design which can easily be determined by experiment with models in tank tests.

Mr. Gibson Knight does not seem to realise the assistance that would be rendered by a committee to aircraft designers if scantling rules were drawn up. For instance, anyone knowing Lloyd's rules for the construction of power boats appreciates how valuable the tables and information given are to designers and builders. Instead of cramping the designers' hands it would provide them with very valuable data and obviate masses of calculations. Mr. Knight is quite correct in stating the supermarine type of construction is practically the same as the P.5 and N.4. All interested in flying boat construction know that the general features of the supermarine type of hull are similar to the above-mentioned types, so it was unnecessary for me to refer to them in detail. I also had dealt with the P.5 and N.4 at greater length in previous papers.

From experience I know exactly how long the boat builders took to do the diagonal planking and the time taken to cover the same area with the fore and aft planking, and have shown comparative figures of the times taken and also the wages paid. Again, anyone who has had experience in laying out fore and aft planking knows that the fairing and tapering each plank is a big job, while the diagonal planking is more or less parallel.

I agree with Captain Sayers that great credit is due to the men who designed and built the first "F" boats, but he is wrong in stating that they received no encouragement from naval architects. I know that the late Major Linton Hope and Captain Shepherd put many suggestions forward. Again, I personally interviewed the designers and builders and pointed out many of the details that were entirely opposed to the usual naval architects' or boat builders' practice, and suggested where the badly designed parts would fail. For instance, the stopping of timbers at the keel, the small connection of bottom planking to keel, discontinuity of strength members, the butting of double planks together, the U boat method of connecting keel to keelson, etc., etc., all of which is never seen in power boats, proved, as I had stated, to be weak and all had to be strengthened up with continuous timbers, etc.

When Major Hope read his paper before this Society he stated that his designs were not as he would have turned out if he had been allowed a free hand; so here again Captain Sayers will see that naval architects have not had the chance which I consider is due to them.

Major A. R. Low's remarks are very interesting and I agree with him that if only the hull had to be considered there would be no apparent limit in sight.

Many theoretical engineers state that 10,000lb. is the limit to the size of flying boats, because the law of dimensions lays down that areas increase as the

square, and weights as the cube, of the dimensions, but this theory has been upset as larger boats have now been flying. Some reasons for the apparent theoretical discrepancy is that the larger the flying boat the more detailed can be the design work and the material used in a more efficient manner; also the factor of strength can be cut down as one does not want to loop or do stunts with a large passenger flying boat.

The question of anti-fouling raised by Colonel the Master of Sempill is one of the most important subjects to be dealt with on flying boat hulls. The bronze powder he mentions has not to my knowledge been used on racing yachts. As the bottoms of these boats are scrubbed every two or three weeks, no advantage is gained by copper sheathing or bronze powdering, but for cruising yachts the powder applied as suggested by Colonel Sempill would prove fairly satisfactory. Many hundreds of experiments have been tried to produce a perfect anti-fouling paint, but this has not yet been invented. Many compositions are in the market at present, but all that can be said of them is that they are more or less successful in retarding or delaying fouling. The success of an anti-fouling paint depends very largely on the method of applying it, and every maker gives instructions with his composition as to how it should be used. One of the important points to be noted is that the composition should be kept well stirred whilst being used as the ingredients are heavy and soon settle to the bottom.

Again, the success of the composition depends greatly on the boat's movements after coating, the time she lies in harbour, the particular seas navigated (whether warm, tropical, or cool), the season of the year, and other matters. A composition may be found quite good for a boat in a certain district, but the same one might be quite useless in another boat differently engaged. It might wash off too quickly, or too slowly, or it might be insufficiently poisonous, or its anti-fouling qualities might not be fully developed at the right time. I think the above will prove to Colonel Sempill that the wrong kind of composition was used on the boats in the south of Italy. It is on these lines that I should recommend research. As it is an established fact that all climates and districts require a different composition, pieces of timber or floats should be tested with various compositions, and types of marine growth noted for each district, and then these particular growths of marine life can be more successfully dealt with. The whole experiment must be carried out where the boat is to be engaged, and by doing this fairly good results should be obtained. Colonel Sempill states that boats moored out for less than a fortnight become very dirty; this should not have been the case and appears to show that the wrong kind of composition must have been used, as when a boat is lying in harbour the contiguous layer of still water may be rendered so highly poisonous as to turn off or destroy any germs essaying to attach themselves, but when at sea, any poison that exudes from the paint is so diluted by the limitless volume of pure water passing over the surface that its deleterious effect becomes inappreciable. The general procedure followed at present is that tests may be made on, say, the river Tyne and a fairly successful paint found for the East Coast, but as the marine life found there is different from that, say, of the south of Italy, the same composition would probably be useless, so here Colonel Sempill has a very wide field for research.

I must thank Mr. Penny for his appreciation of my paper, and as is to be expected, as he is a naval architect, we have many views in common. Had I included a discourse on superstructure and engine installation in the paper, I am afraid my audience would have expressed the opinion that the paper was too lengthy.

The subject of flying boats, as a whole, embraces so many different phases and questions that it is impossible to deal with all in one paper, so there exists a splendid opportunity for other papers on such details as I intentionally omitted. Doubtless Mr. Penny, being a member, will favour the Society with his views

in the form of a paper. With reference to his remarks on resistance or drag set up by the superstructure, I heartily agree.

I do not think I have created a false impression with reference to the supermarine boats, as my remarks on circular hull construction applied to all boats of this type; I took the original A.D. as a basis for discussion and did not discuss the A.D. hull to the exclusion of the N.4, P.5, etc.

Mr. Penny is quite correct in stating that the present methods of constructing the A.D., P.5 and N.4 flying boats is not new, and has been common boat building practice for years, but I must take exception to the inclusion of the bottoms of the F.5, as I am sure that if Mr. Penny more closely examines the construction of the F.5 bottom he will agree that it cannot be classed as boat building practice.

Referring to Mr. Penny's remarks on my critics, if he will look through my replies to Wing-Commander Cave, Mr. Gibson Knight and Colonel the Master of Sempill, he will find that I have agreed with him.

THE EFFECT OF ATMOSPHERIC PRESSURE AND TEMPERATURE UPON THE PERFORMANCE OF A PETROL ENGINE.

THE USE OF SUPERCOMPRESSION IN AERO ENGINES.

BY E. G. RITCHIE, D.SC., A.M.INST.C.E., A.M.I.MECH.E., OF THE RESEARCH ASSOCIATION OF BRITISH MOTOR AND ALLIED MANUFACTURERS.

The efficiency of all internal combustion engines is influenced to a large degree by the density of the charge prior to ignition. In the stationary engine operating at normal ground density, the variation in compression pressure throughout the range of working conditions is so small as to have no appreciable effect upon engine performance. In the aero engine, however, the conditions obtaining in flight are such as to produce wide variation in the suction pressure and therefore in the compression pressure due to changes in atmospheric density.

Table 1 has been prepared to show the variation in air pressure, temperature and density with height, the figures given representing the mean conditions obtaining in the south of England.

TABLE 1.

Altitude in feet ...	0	5,000	10,000	15,000	20,000	25,000
Pressure in lbs. sq. in.	14.65	12.35	10.15	8.25	6.70	5.45
Temperature °C ...	+11.0	+4.0	—4.5	—15.0	—26.0	—37.5
Density in lbs. per cu. ft.	.0785	.0676	.0570	.0486	.0415	.0346

From the above table it will be realised that the wide range of conditions under which the aero engine is required to operate places this form of prime mover in a class altogether by itself.

In what follows, it is proposed to discuss the effect of change in atmospheric pressure and temperature upon the performance of the normal aero engine, and to consider the influence of compression ratio upon the efficiency of an engine when operating under the conditions obtaining at high altitude.

The effect of air density upon engine performance is not capable of presentation in simple form, as different engines are found to react differently towards changes of pressure and temperature. In what follows the effect of these two variables is treated separately.

(1.) Effect of Air Pressure on the Performance of the Normal Aero Engine.

The weight of air entering the cylinder of an internal combustion engine is proportional to the density of the charge, and if the temperature remains constant, is therefore proportional to the pressure, on the assumption that all other variables such as engine adjustment, speed, etc., remain constant. The theoretical mean pressure may be readily shown to be given by

$$\eta(P_3 - P_2)/(\gamma - 1)(r - 1).$$

Where $(P_3 - P_2)$ is the theoretical rise in pressure following ignition, η is

the theoretical thermal efficiency, γ is the adiabatic exponent for air, and r is the compression ratio.

Since η is dependent only upon the temperature cycle, the theoretical mean pressure is seen to be directly proportional to $(P_3 - P_2)$ and therefore directly proportional to the initial pressure, if the initial temperature and the compression ratio remain constant. It would thus appear that the indicated mean effective pressure and, therefore, the i.h.p. of an engine, is directly proportional to density, if the air temperature remains constant.

No data as to variation in i.h.p. with density is available, but deductions made from observations on the variation of b.h.p. with density would appear to indicate that the above relationship substantially holds, down to a density corresponding to approximately 60 per cent. of ground density.

Observations made on several aero engines under artificial altitude conditions, with a view to investigating the variation in b.h.p. with air density, are shown in Fig. 1. In these tests ground temperature conditions were maintained constant throughout, the density being reduced by reducing the inlet and exhaust pressures.

The various engines tested were as follows :—

(1) 12-cylinder Vee aluminium cylinder air-cooled engine, bore 100 mm., stroke 140 mm., compression ratio 4.7 : 1, speed 1,600 r.p.m.*
(2) 12-cylinder Vee cast-iron cylinder air-cooled engine, bore 100 mm., stroke 140 mm., compression ratio 4.4 : 1, speed 1,400 r.p.m.†
(3) 8-cylinder Hispano Suiza water-cooled engine, bore 120 mm., stroke 130 mm., compression ratio 4.6 : 1, speed 1,550 r.p.m.‡

Each engine was run under normal full throttle conditions at the speeds indicated above, the petrol flow being adjusted under each pressure condition to give maximum load on the lowest possible fuel consumption.

In Fig. 1, brake horse-power and petrol consumption per hour, expressed as a percentage of ground power and consumption, are plotted against air pressure expressed as a percentage of ground pressure.

(2.) Brake Horse-Power and Air Pressure.

The plotted results indicate that in each engine the b.h.p. falls off at a sensibly constant rate down to a pressure corresponding to approximately 60 per cent. of ground pressure. The rate of decrease is evidently dependent upon compression ratio, increasing with decrease in compression ratio.

Engines (1) and (2) were tested under identical conditions and under the same authority; the results may therefore be taken as directly comparable. From the plotted results it will be seen that while in the former engine, the b.h.p. is directly proportional to air pressure, in the latter, the b.h.p. falls off more rapidly than air pressure, the difference amounting to nearly one per cent. for each 10 per cent. drop in air pressure. With air pressures lower than about 60 per cent. of ground pressure the rate of decrease of b.h.p. increases rapidly, the increase being approximately the same in each case.

Tests carried out on engine No. 3, under the authority of the U.S. Bureau of Standards, show that the effect of reduction in atmospheric density increases with increase in engine speed as indicated in Table 2.

* Observations by Professor A. H. Gibson, D.Sc., M.Inst.C.E., M.I.Mech.E., at the Royal Aircraft Establishment.
† Observations made by the Author at the Royal Aircraft Establishment.
‡ U.S.A. Bureau of Standards.

TABLE 2.

Air Pressure.		Engine R.P.M.			
Ins. of Mercury.	Relative.	1,300	1,700	2,100	Relative b.h.p.
29.9	100.0	100.0	100.0	100.0	
24.4	81.6	81.8	82.0	81.4	
19.7	65.9	65.7	65.2	64.3	
14.8	49.5	48.9	48.4	47.4	
10.1	33.8	33.6	32.1	30.4	

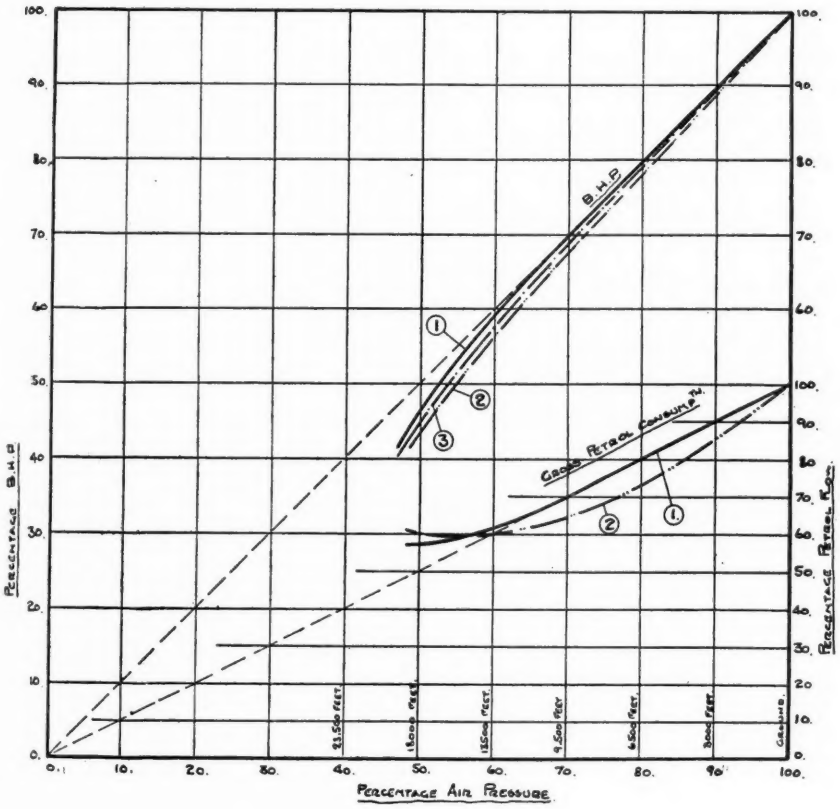


FIG. 1.

(3.) Petrol Consumption and Air Pressure.

The observations plotted in Fig. 1 show that the gross fuel consumption per hour is nearly proportional to air pressure down to a density corresponding to between 60 per cent. and 70 per cent. of ground density. With densities lower than this, the consumption decreases less rapidly than air pressure. The con-

sumptions in lbs. per b.h.p. per hour corresponding to the plotted results for engines 1 and 2 are as follows :—

TABLE 3.

	Relative Air Pressure.					
Engine.	1.000	.900	.800	.700	.600	.500
(1)	.533	.533	.533	.541	.581	.687
(2)	.563	.563	.563	.578	.651	.793

From the above it will be seen that while the petrol consumption per b.h.p. per hour is sensibly constant in both tests down to a pressure of 70 per cent. to 80 per cent. of ground pressure, beyond this point, the consumption increases rapidly with diminishing density. The petrol flow in the case of the Hispano Suiza engine tests was not observed. The consumption on this engine under normal ground conditions is however somewhat higher than on No. 1 engine, and is lower than No. 2 engine. In the tests on engines 1 and 2, arrangements were made for controlling the petrol flow, and under each test condition, this was adjusted to give minimum petrol consumption consistent with the maintenance of full load. Any reduction in the petrol consumption below the figures given resulted in a drop in power over the whole range of pressures tested. It would therefore appear that the rate at which the b.h.p. decreases with diminishing density is greater in an engine having a low thermal efficiency. In this regard, it is noteworthy that the power of a rotary engine falls off much more rapidly with height than does a stationary engine of either the radial or line type. In the normal rotary engine, the induction system is recognised to be faulty, and conditions are such as to militate against the development of high thermal efficiency. The influence of air density on thermal efficiency is further referred to in para. 12.

(4.) Effect of Air Temperature on Engine Performance.

Since the power output of a petrol engine is dependent upon the weight of charge drawn into the cylinder, the effect of an increase in air temperature—other conditions remaining constant—may therefore be expected to reduce the power output, and a decrease in air temperature the reverse. The effect of air temperature variation upon power is not however a primary one, the quantitative effect depending upon carburettor and induction pipe design, mixture strength, etc. During its passage from the carburettor to the cylinder, the petrol is partially vaporised, absorption of the latent heat necessary for this process causing a drop in temperature as between the inlet air and the charge in the induction pipe. The nett result of this is, that the density of the charge is effected by change in air temperature to a lesser degree than that of the intake air. Increase in air temperature not only causes increased atomisation at the jet, due to decrease in the viscosity and surface tension of the petrol, but also gives rise to greater evaporation in the induction pipe. Even in the simple unheated induction system, conditions are thus seen to be complex. In the multi-cylinder engine, fitted with a heated induction pipe, further complications arise. Preheating of the charge, while reducing the charge density, improves the distribution. Reduction of the charge weight tends to reduce the power output, while better distribution tends to increase it.

As showing the effect of change in inlet air temperature on the performance of a single-cylinder water-cooled petrol engine, results obtained in a series of tests carried out by the author are discussed below.*

The tests were conducted on a single cylinder taken from the 300 h.p. Fiat Aero Engine, the bore and stroke of which are 160 mm. and 180 mm. respectively.

* Advisory Committee for Aeronautics, I.C.E. Report 281.

The observations were made with a compression ratio of 6.0 : 1. Arrangements were made whereby the inlet and exhaust pressure could be regulated, and the inlet air temperature varied between — 10° C. and + 50° C. The carburettor and induction pipe were unjacketted. The tests were carried out at a constant engine speed of 1,550 r.p.m., observations being made over a range of absolute air pressures varying from 10 to 19ins. of mercury. Under each condition as to pressure and temperature, the petrol flow was adjusted to give maximum load on the lowest possible consumption. Induction pipe temperatures were measured by means of a shrouded platinum-iridium thermocouple. The results obtained are shown in Fig. 2, and are discussed below.

(5.) Air Temperature and Charge Temperature.

The induction pipe temperature observations indicate that the temperature difference between the inlet air and the charge in the induction pipe is sensibly independent of air pressure, but increases with increase in intake air temperature. The mean results obtained in each series were as follows :—

TABLE 4.

Intake air temperature. °C.	—8.8	+ 13.0	+ 45.0
Temperature charge in induction pipe. °C	—20.6	—11.7	+ 6.3
Temperature difference between intake air and charge. °C.	11.8	24.7	38.7

The relationship between the inlet air temperature and the induction pipe temperature is substantially represented by

$$T = .515\theta - 16.9.$$

Where T is the induction pipe temperature in °C. and θ is the intake air temperature in °C. the relationship between induction pipe temperature and intake air temperature depends essentially upon the mixture strength, the degree of atomisation at the jet, and the subsequent condition of the mixture in the induction pipe. Tests carried out by Dr. A. H. Gibson on a single-cylinder air-cooled engine gave the following relationships :—

$T = \theta^{1.5}/13$ for normal mixtures (.45/.55lbs./b.p.h./hr.)
$T = \theta/2$ for rich mixtures (.67/.81lbs./b.h.p./hr.)

while the relationships found to hold in the case of engines 1 and 2 of para. 2 were as follows :—

Engine 1. $T = .3\theta - 4$.
Engine 2. $T = .25\theta$.

It would thus appear that the drop in temperature across the carburettor varies widely in different engines, and is in fact a function of so many variables, that no relationship having a general application is possible of formulation. With a mixture strength of 14lbs. of air per lb. of petrol, the temperature drop accompanying complete vaporisation of the fuel may be shown to be approximately 22° C. In the normal induction system vaporisation is incomplete, and with a mixture strength of the above composition the temperature drop is less than that given. With mixtures richer that 14 to 1, the temperature drop is proportionately greater, due to the relatively greater evaporation of the lower boiling fractions.

(6.) Air Temperature and Power Output.

From Fig. 2 it will be seen that the b.h.p. increases with a reduction in air temperature over the range of temperature tested. The temperature effect is dependent upon air pressure, diminishing with increase of pressure. The per-

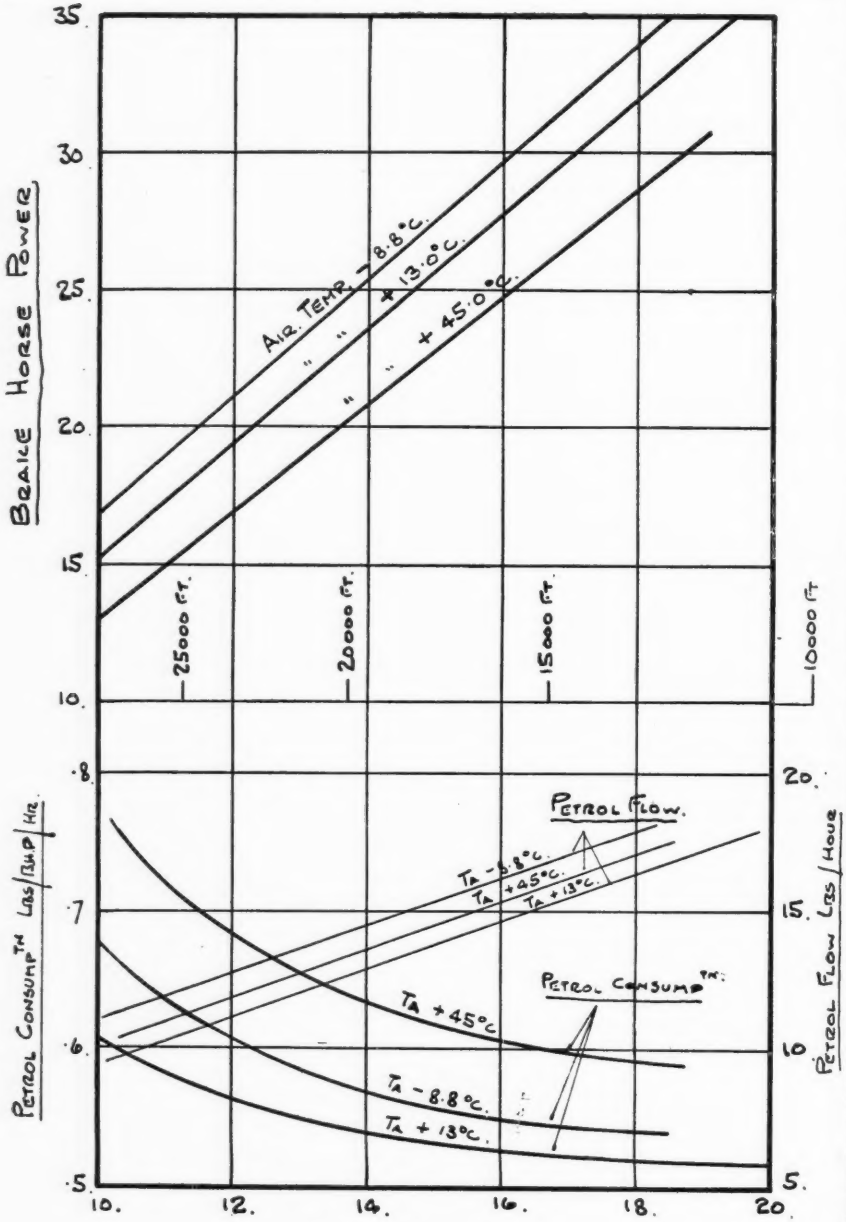

BRAKE HORSE POWER
AIR TEMP. −8·8°C.
" " +13·0°C.
" " +45·0°C.
25000 FT.
20000 FT.
15000 FT.
10000 FT.
PETROL CONSUMPTN LBS/BHP/HR.
PETROL FLOW.
TA −8·8°C.
TA +45°C.
TA +13°C.
PETROL CONSUMPTN.
TA +45°C
TA −8·8°C.
TA +13°C.
PETROL FLOW LBS/HOUR
ABSOLUTE AIR PRESSURE.
INCHES OF MERCURY.

FIG. 2.

centage increase or decrease in b.h.p. with temperatures below or above 0° C. has been calculated over a range of absolute air pressures from 10 to 18ins. of mercury. Taking the b.h.p. developed with an air temperature of 0° C. as a basis of comparison, the b.h.p. developed with a temperature θ° C. is given by $P_0(1 \pm \theta/K)$.

Where P_0 is the b.h.p. developed at 0° C., the term θ/K being added or subtracted according as θ is below or above zero.

The value of K increases with a decrease in absolute air pressure as shown below.

TABLE 5.

Absolute air pressure in ins. of Mercury ...	10.	12.	14.	16.	18.	29.9
Value of K	187.	243.	290.	339.	386.	between 500 and 600

The value of K at a pressure of 29.9ins. has been obtained by extrapolation.

Tests carried out by Dr. A. H. Gibson on an aluminium air-cooled single-cylinder engine under ground pressure conditions, showed the necessary power correction for normal mixtures to be $(1 \pm \theta^{1.5}/3{,}500)$, and for rich mixtures $(1 \pm \theta/546)$. The latter is in fair agreement with the extrapolated value given in Table 5. From the above it would appear that the value of K depends not only upon the air temperature, but also upon the mixture strength, decreasing with increasing richness. The decrease in K with diminution in air pressure observed in the series of tests under discussion, is partly due to this cause, the results obtained showing an increase in consumption with diminishing air pressure as indicated in Fig. 2. The value of K will also vary with the type of carburettor employed, depending upon the degree of mechanical atomisation at the jet, and upon the design of the induction pipe.*

(7.) Induction Pipe Temperature and Power Output.

As indicated in para. 6, the effect of variation in air temperature upon the power output of an engine differs in different engines, and for this reason any relationship connecting the two is unsatisfactory. Such data as is available does, however, point to a definite relationship between the power developed and the temperature of the charge in the induction pipe.

From the tests referred to in para. 4 the following figures have been deduced :—

TABLE 6.

Mean Inlet Air Temp. ° C.	Absolute Air Pressure in inches of Mercury. 10.	12.	14.	16.	18.	
—8.8	4120.	5330.	6470.	7420.	8330.	Values of b.h.p. × abs. temp. of charge in induction pipe.
+13.0	4020.	5200.	6350.	7310.	8330.	
+45.0	3500.	4700.	5760.	6850.	8030.	

From the above it will be seen that the product of the b.h.p. and the absolute charge temperature is sensibly constant for air temperatures of —8.8° and +13.0° C., under similar air pressure conditions, the error made in assuming inverse proportionality between absolute charge temperature and power output nowhere exceeding one per cent. The agreement is not so close in the tests carried out with an air temperature of +45° C., particularly with the lower air

* For further data on the influence of induction pipe design upon power variation with temperature, the reader is referred to "Aero Engine Efficiencies," Professor A. H. Gibson, D.Sc., M.Inst.C.E., M.I.Mech.E., Transactions of the Royal Aeronautical Society, vol. 3.

pressures. It is to be observed, however, that with this temperature the petrol consumption was excessive, and the conditions as to temperature were such as are not likely to occur under actual conditions of flight.

Experiments carried out by Dr. A. H. Gibson on a single-cylinder air-cooled engine showed that at constant air temperature, the effect of engine-speed, and therefore of gas-speed, on induction pipe temperature was relatively small, while a change in air temperature over a range from +2° C. to +82° C. had very little effect upon cylinder temperature, and therefore upon heat loss to the walls. In this respect, increase in air temperature as effecting increase in wall temperature appears to be counterbalanced by the reduction in power output as effecting reduction in wall temperature.

The evidence given above, together with much confirmatory evidence, would appear to establish the fact that over a wide range of pressure and temperature, and with normal mixture strengths, the power output of a petrol engine is inversely proportional to the absolute temperature of the charge in the induction pipe.

(8.) Effect of Air Temperature on Petrol Consumption.

Experience shows that the majority of petrol engines develop maximum power on a mixture strength considerably richer than that corresponding to maximum economy, the excess of petrol being mainly required to prevent the charge rising to its spontaneous ignition temperature. Increase in air temperature results in higher compression temperature, and in consequence, under maximum load minimum consumption conditions, a greater excess of petrol is required if spontaneous ignition of the fuel is to be prevented. Conversely, a limited reduction in air temperature may be expected to effect a reduction in fuel consumption. Apart from the conditions obtaining in the cylinder, however, the air temperature has a material influence upon the condition of the charge in the induction pipe, and therefore upon the fuel consumption.

The viscosity of the fuel increases, while the vapour pressure decreases, with reduction in temperature, both of which factors adversely affect the condition of the charge. In practice, decrease in air temperature may be expected to have a beneficial effect upon fuel consumption down to a point at which non-homogeneity of the mixture begins to interfere with charge distribution. Beyond this point, reduction in air temperature will obviously have an adverse effect upon fuel consumption. From the nature of the case, the effect of temperature upon fuel consumption will differ in different engines. In the multi-cylinder engine, pre-heating of the charge is found to be essential under the low temperature conditions obtaining at high altitude, due to the adverse effect of low temperature on charge distribution. Under ground temperature conditions, with a well-designed induction system, jacketing has invariably the effect of reducing the power output of the engine and of lowering its thermal efficiency.

The test results plotted in Fig. 2 show that whereas the b.h.p. increases with decrease in air temperature, over the range of temperatures tested, minimum petrol consumption per b.h.p. per hour was obtained with a mean temperature of + 13° C. The results obtained indicate that in this engine an air temperature of approximately 0° C. corresponds to conditions of maximum efficiency. Temperatures lower than this have evidently a detrimental effect upon the condition of the charge. Using the results obtained with an air temperature of 13° C. as a basis of comparison, it will be seen that with an air temperature of 45° C. the consumption per b.h.p. per hour is approximately 14 per cent. greater with an absolute air pressure of 18 inches of mercury, the difference increasing to 21 per cent. with an air pressure of 12 inches of mercury. The corresponding increase with an air temperature of — 8.8° C. is approximately 4 per cent. with the higher pressure and 6 per cent. with the lower pressure.

(9.) Effect of Compression Ratio on the Performance of an Aero Engine Operating under Reduced Density Conditions.

The theoretical efficiency and theoretical mean pressure of an internal combustion engine increase indefinitely with increase in the ratio of compression. In a petrol engine, operating on full throttle at a given air density, the extent to which the compression may be raised depends upon a number of factors, of which the spontaneous ignition temperature of the fuel is the most important. For normal combustion this temperature must not be exceeded during the compression stroke, and in the average well designed engine operating on the ground it is found that a compression ratio of from 5.0 to 5.3 : 1 is the maximum permissible, consistent with the maintenance of normal operation on full throttle.

Since the temperature at the end of compression is theoretically dependent only upon the ratio of compression and the initial temperature, the compression temperature would appear to remain constant with diminishing density if the initial temperature remains constant. Under engine conditions, however, the compression temperature is dependent upon cylinder temperature, and this decreases with decrease in the weight of charge dealt with per cycle and therefore with decrease in atmospheric density.

In the case of an aero engine operating under reduced density conditions at altitude, the initial pressure and temperature, and hence the compression pressure and temperature are considerably lower than under ground conditions, and in consequence, in the normal aero engine adjusted to give the maximum permissible compression on the ground, the temperature at the end of compression is well below the spontaneous ignition temperature of the fuel. In effect, an engine which is adjusted to give the maximum possible efficiency on full throttle on the ground is essentially operating under conditions of low efficiency at altitude.

The following tests were carried out by the author, with a view to investigating the effect of high compression upon the performance of an aero engine under reduced density conditions.

The investigation was conducted in the altitude test house at the Royal Aircraft Establishment.* A single cylinder from the 300 h.p. Fiat aero engine was employed, and arrangements were made whereby the inlet and exhaust pressure could be reduced to that corresponding to any altitude up to approximately 30,000 feet. The temperature of the intake air was maintained sensibly constant throughout the tests, varying from 13° C. to 17° C. In each test the quantity of heat given to the jackets and the heat loss in the exhaust were determined, an exhaust gas calorimeter being employed for the latter purpose. The carburettor was fitted with a variable jet, and under each test condition the petrol flow was adjusted to maintain maximum load on the lowest possible petrol consumption. The spark advance was maintained at 35° C. except where mentioned. Precautions were taken to maintain constant oil temperature throughout the series, and correction was made for mechanical losses in the test bed not directly attributable to the cylinder. These include the mechanical losses in the bed apart from crankshaft and piston line losses, such as centrifugal pump drive, etc. The b.h.p. absorbed in such losses under the conditions of the test was separately determined by means of an electric dynamometer.

Tests were made with compression ratios of 4.0, 4.8, 6.0 and 7.6 : 1. With the first three ratios the standard piston was employed, the clearance volume being adjusted by shims under the cylinder flange. The highest compression was obtained by the use of a special piston similar in general design to the standard piston, but having the crown chamfered off at the edge to prevent over-running of the sparking plug. The fuel employed was Shell Aviation Spirit having a

* Advisory Committee for Aeronautics, I.C.E. Report, 281.

density of .715 and a nett calorific value of 18,600 B.Th. U.'s per lb. The tests were conducted at a speed of 1,550 r.p.m.

(10.) Variation in B.H.P. and Petrol Consumption with Compression Ratio.

The variation in b.h.p. with air pressure for the various compression ratios is shown graphically in Fig. 3, all of the observations plotted being obtained on

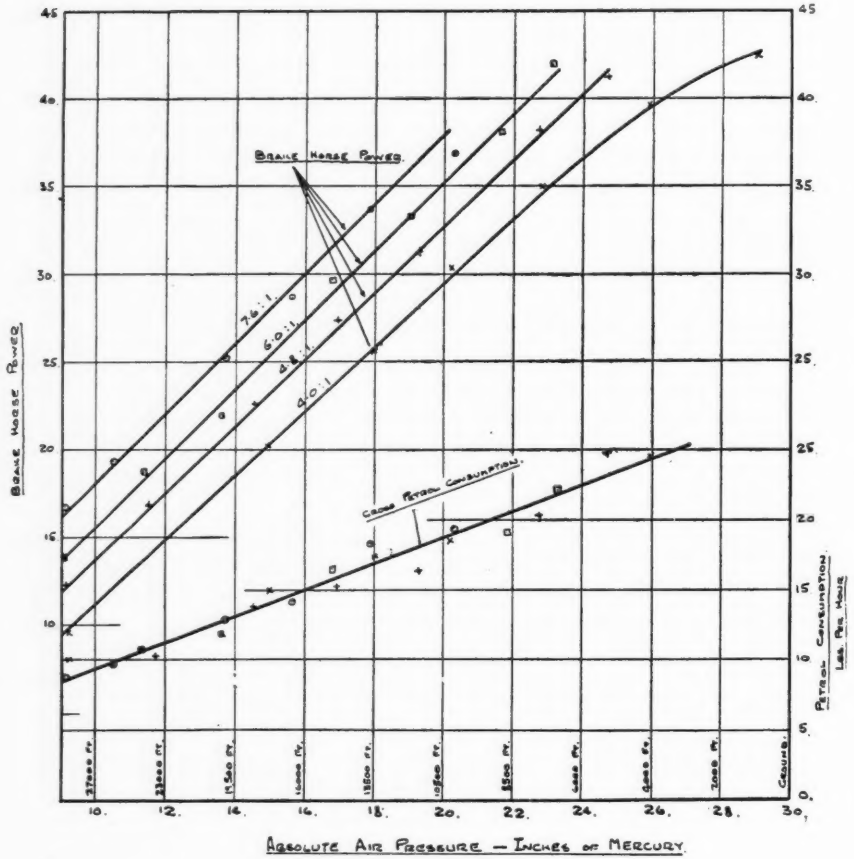


Fig. 3.

full throttle. The variation in gross petrol flow is also shown in Fig. 3, while petrol consumptions per b.h.p. per hour are plotted in Fig. 4.

The maximum air pressure at which the engine could be run on full throttle without detonation with the highest compression ratio tested, was found to be approximately 20 inches of mercury. Using the b.h.p. developed with each ratio at this air pressure as a basis of comparison, the percentage drop in power and petrol flow with diminishing density have been calculated and are shown plotted against percentage air pressure in Fig. 5.

(a) Brake Horse-Power.

An examination of Fig. 3 shows that under reduced density conditions substantial increase in power is obtainable by the use of higher compressions than are normally employed in aero engines. The normal compression ratio of the 300 Fiat engine is 4.75 to 1. Using the results obtained in the single cylinder

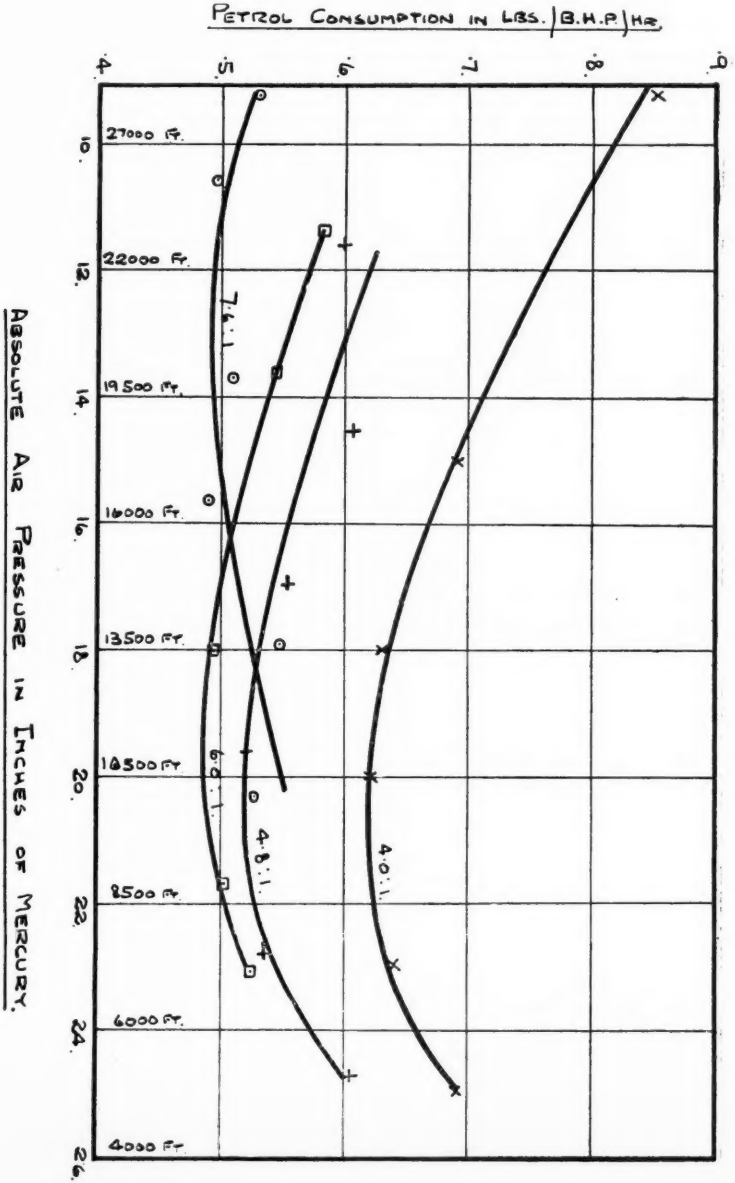


FIG. 4.

unit with a compression ratio of 4.8 as a basis of comparison, the percentage gain in b.h.p. with compression ratios of 6.0 and 7.6, and the percentage loss in b.h.p. with the 4.0 compression ratio have been calculated for various air pressures and are shown graphically in Fig. 6. The plotted results of Fig. 6 show that the gain in power obtainable by the use of high compression increases rapidly as the density diminishes. The results obtained with a ratio of 4.0 : 1 serve to indicate the relative inefficiency of compressions lower than the normal, particularly under low density conditions.

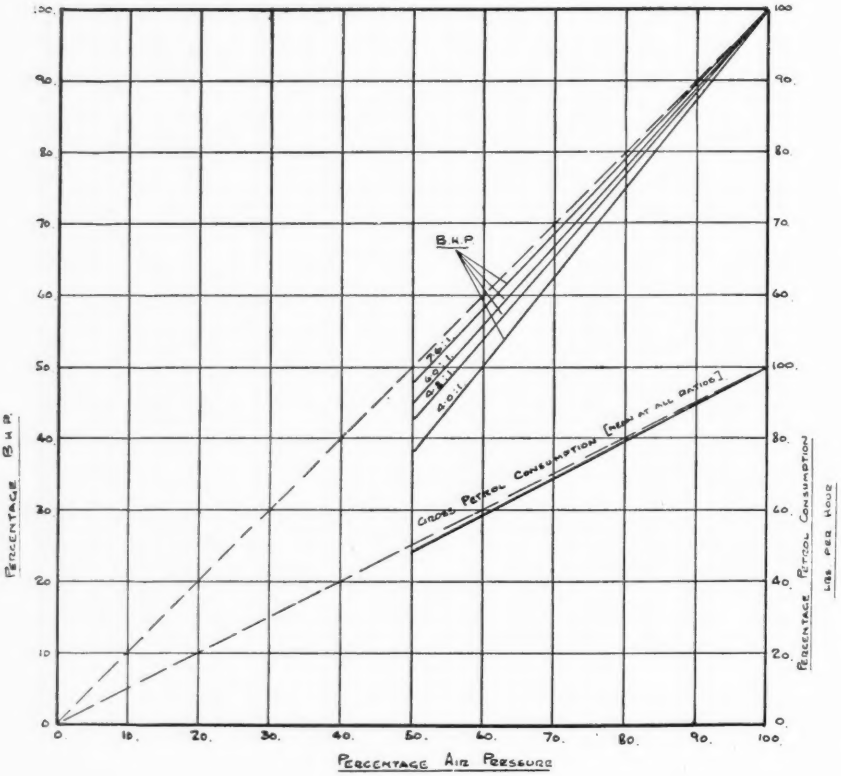


Fig 5

The dotted lines of Fig. 6 represent the theoretical gain on or loss in b.h.p. with reference to a ratio of 4.8 for the various ratios tested, and refer to constant initial temperature conditions. It is of interest to note that while the observed values are in close agreement with the theoretical values at pressures in the neighbourhood of 20 inches of mercury and with pressures in excess of this, the actual increase in b.h.p. obtainable with increased compression at pressures lower than this exceeds the theoretical increase, the difference increasing with decrease in density. The subject is dealt with at greater length in para. (12).

From Fig. 5 it will be observed that the relationship between percentage power and percentage pressure is a linear one for all compressions and over the range of pressures tested. The rate of decrease of power with pressure is dependent upon compression ratio, decreasing with increase in compression ratio. With

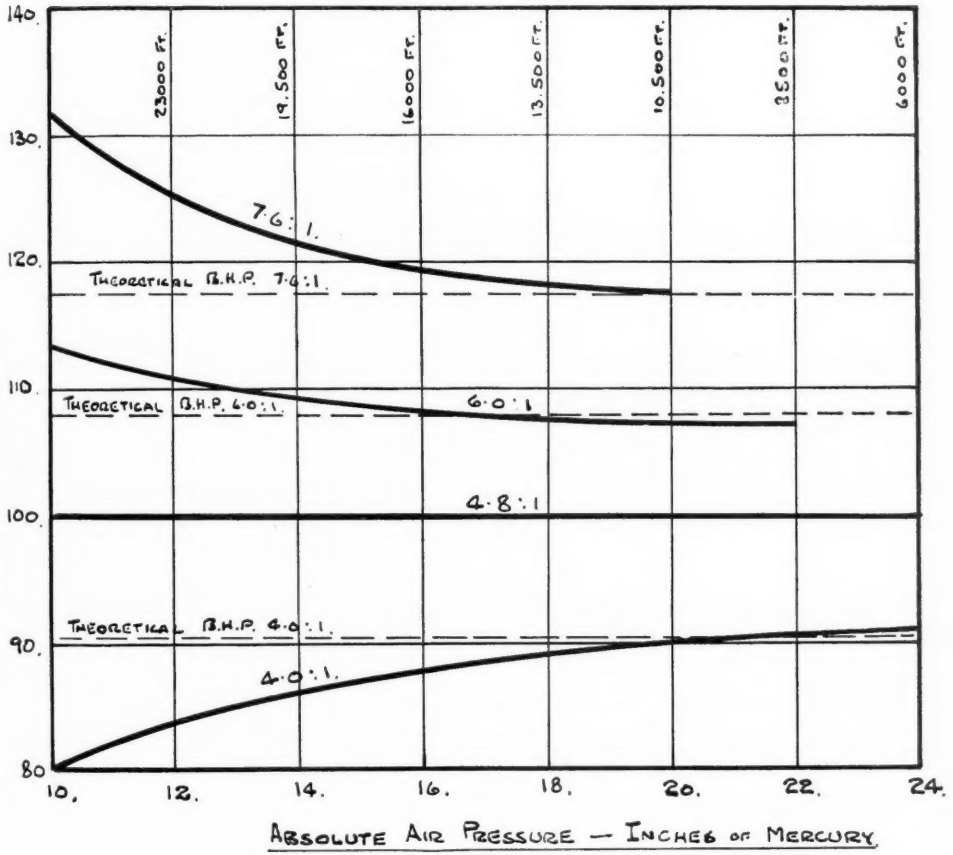


Fig. 6.

a pressure equivalent to 50 per cent. of the standard pressure chosen for comparison, the percentage b.h.p. with each ratio is as follows:—

TABLE 7.

Compression Ratio.	4.0	4.8	6.0	7.6
Percentage b.h.p. ...	38.0	42.5	45.0	48.0

The 300 h.p. Fiat engine with standard compression develops approximately 244 h.p. on the ground at 1,550 r.p.m. Assuming that the effect of density is

the same in the multi-cylinder engine and in the single-cylinder unit, and neglecting the effect of temperature, the probable output of the engine at various altitudes and with various compression ratios is given in Table 8.

TABLE 8.

Altitude in feet.	Compression Ratio. 4.0	4.8	6.0	7.6
10,000 ...	175	194	208	—
15,000 ...	135	152	164	181
20,000 ...	101	118	129	144
25,000 ...	73	89	100	114
30,000 ...	51	65	75	88

The figures given above indicate the importance of high compression in relation to the performance of an aero engine under the conditions obtaining at altitude.

(*b*) Petrol Consumption.

Taken over the range of pressures tested, the petrol consumption per b.h.p. per hour decreases with increase in compression ratio. The means of all observations for each ratio are as follows:—

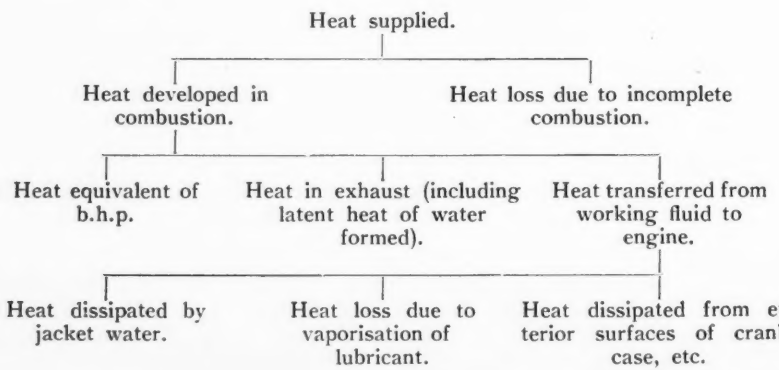
TABLE 9.

Compression Ratio.	4.0	4.8	6.0	7.6
Mean petrol consumption lbs./b.h.p./hour ...	.70	.56	.52	.51

The gross consumption in lbs. per hour for each test is shown in Fig. 3. The plotted results show that for all compressions the gross petrol consumption for the same absolute air pressure is sensibly constant. It therefore appears that under the reduced density conditions obtaining at altitude, the improvement in the performance of a machine, obtainable by increasing the compression ratio of the engine, is secured without increasing the weight of petrol carried for a given endurance. This enables a greater air mileage per gallon to be obtained, and for the same useful load carried, a greater range of flight than is obtainable with the normal engine.

(11.) Heat Distribution. Thermal Efficiency.

The heat energy supplied to the engine in the form of fuel is expended as follows:—


Heat supplied.
Heat developed in combustion.
Heat loss due to incomplete combustion.
Heat equivalent of b.h.p.
Heat in exhaust (including latent heat of water formed).
Heat transferred from working fluid to engine.
Heat dissipated by jacket water.
Heat loss due to vaporisation of lubricant.
Heat dissipated from exterior surfaces of crankcase, etc.

In the present series of tests no exhaust gas analyses were made, and consequently the quantity of heat lost in unburnt gases could not be accurately determined. In drawing up a heat balance for each series of tests, the heat loss in unburnt gases and that lost in radiation have been lumped together and obtained by difference. The heat loss in the exhaust includes the residual heat after passing the calorimeter. The latent heat of vaporisation of the water formed has been deducted as the lower calorific value of the fuel has been employed.

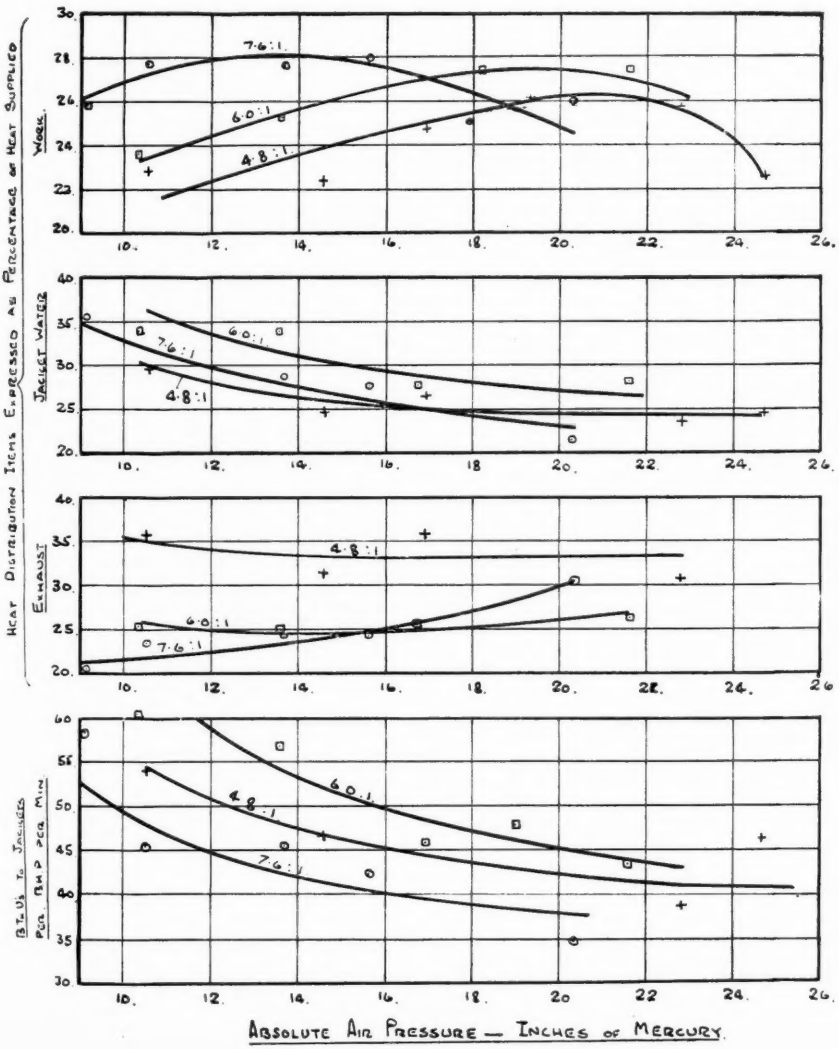


Fig 7.

The heat distribution for the 4.0 : 1 compression ratio was not observed as this ratio is too low to be of practical interest.

The variation in the thermal efficiency, the percentage of the total heat given to the jackets and that lost in the exhaust with varying air pressure and compression ratio are shown in Fig. 7.

The mean brake thermal efficiencies taken over the whole range of pressures tested are 0.268, 0.260 and 0.246, with compression ratios of 7.6, 6.0 and 4.8 respectively.

With regard to the jacket and exhaust losses, the apparent irregularity of the results obtained with the highest compression ratio is probably due to the fact that with this adjustment the sparking plug was partially blanked by the piston at the point of ignition. The piston edge was chamfered off to clear the plug, and this would undoubtedly have a directive effect upon the flame wave. Such directive action would doubtless result in higher piston temperature, and in consequence a greater heat loss to the lubricant. With the lower compression ratios, the standard piston was employed.

A comparison of the results obtained with the 6.0 : 1 and the 4.8 : 1 ratio indicates that the amount of heat given to the jackets per unit of heat supplied, increases with an increase in compression ratio and with a reduction in air pressure. The results also indicate that the amount of heat passing into the jacket water per horse-power per minute increases both with an increase in compression ratio and with a reduction in air pressure as shown in Fig. 7. A comparison of the results obtained with these two ratios is given below.

TABLE 10.

	Heat given to Jacket Water B.Th.U's per Min.					
Compression.	Air Press. 13in. Mercury.		Air Pressure 18in. Mercury.		Air Pressure 23in. Mercury.	
Ratio.	per B.H.P.	Total.	per B.H.P.	Total.	per B.H.P.	Total.
4.8 : 1	50.5	985	44.2	1282	42.4	1620
6.0 : 1	56.5	1215	47.0	1468	44.1	1809

The three air pressures compared correspond approximately to 21,000, 12,500 and 7,000 feet respectively. At these three altitudes the higher compression ratio gives 10 per cent., 8½ per cent. and 6½ per cent. more power, while the heat given to the jackets per unit of power is 12 per cent., 6 per cent. and 4 per cent. greater than with the lower compression ratio.

An abstract of the heat distribution and its variation with compression ratio is given below. In this case values have been obtained by taking the means of all observations made with each compression ratio.

TABLE 11.

Comp. Ratio.	B.Th.U's Supplied.	B.Th.U's in Work.	B.Th.U's to Jackets.	B.Th.U's Exhaust.	B.Th.U's in Radiation, etc., by difference.
7.6 : 1	100	26.8	25.5	24.7	23.0
6.0 : 1	100	26.0	29.4	25.6	19.0
4.8 : 1	100	24.6	25.1	34.2	16.1

The last column in Table 11 has been obtained by difference. As will be seen, the percentage of the available heat unaccounted for as work, jacket, or exhaust heat is very considerable. The mean air-petrol ratio throughout the tests was probably in the neighbourhood of 12 or 13 of air to 1 of petrol. With a ratio of 13 : 1, the probable exhaust gas analysis is as follows:—

CO_2	CO	H_2	CH_4
12.5%	2.6%	0.9%	0.3%

With this mixture strength, the percentage of the total heat liberated in the cylinder is approximately 90 per cent., leaving some 10 per cent. in the form of unburnt fuel passing into the exhaust. The balance of unaccounted losses is attributed to radiation and to vaporisation of the lubricant from the piston and internal cylinder surfaces. The heat loss due to radiation from the external cylinder and crankcase surfaces was found to be approximately 2 per cent. of the heat supplied under each test condition.

With this correction the heat loss attributable to oil vaporisation is approximately 11 per cent., 7 per cent. and 4 per cent. of the total heat given in each case. These figures, though only approximate, serve to indicate the relatively high thermal losses in the petrol engine attributable to oil vaporisation.

(12.) General Discussion of Data Obtained.

Practically no information is available as to the behaviour of petrol-air mixtures when exploded in a closed vessel. Test results obtained by Messrs. Bairstow and Alexander on the effect of density upon the maximum pressure and rate of explosion in coal-gas-air mixtures are, however, available and are of interest in the present instance as affording a probable explanation of the various phenomena observed in the engine tests discussed.

In these tests a closed explosion vessel having a diameter of 10in. and a length of 18in. was employed, and observations were made with initial pressures ranging from approximately 7lbs. per square inch to 45lbs. per square inch, and for mixtures strength of 6:1 and 10:1 by volume. The former mixture is approximately that giving maximum explosion pressure. The maximum pressure and the time taken to reach that maximum were recorded by an indicator, while the temperature of explosion was also observed.

The experimental results obtained by Messrs. Bairstow and Alexander show that the proportional temperature drop, *i.e.*, the proportional heat flow from the fluid to the walls, increases with reduction in density and with increase in mean gas temperature.

The relative heat loss to the walls with various initial pressures and with mean gas temperatures of 1,200° C. and 1,600° C. is indicated in Table 12.* The figures given for pressures in excess of 45lbs. per square inch have been obtained by extrapolation.

TABLE 12.

Initial Pressure in lbs./sq. inch.	20	30	40	50	60	70	80
Mean temp. 1,200° C.	2.36	2.03	1.73	1.42	1.21	1.09	1.00
Mean temp. 1,600° C.	—	2.66	2.16	1.74	1.41	1.13	1.01

Relative Heat Loss to Walls.

While the proportional heat flow from the fluid to the walls increases with reduction in density, the absolute heat flow per unit of wall area will evidently decrease with reduction in density as the absolute heat flow depends upon the weight of fluid in contact with the walls, and this is directly proportional to density.

The results discussed above are not directly applicable to the petrol engine, as the fuel tested was a mixture of coal gas and air. Notwithstanding this, the results given are useful in the present instance, as offering an explanation of the observed effect of compression ratio upon the performance of an engine operating under reduced density conditions, and also as suggesting a reason for the difference in performance between one engine and another.

* From data given in "Gas, Petrol and Oil Engines," Sir Dugald Clerk, D.Sc., F.R.S., M.Inst.C.E.

In brief, the experiments of Bairstow and Alexander point to the conclusion that in an internal combustion engine the proportional heat loss to the walls increases as the density of the charge prior to ignition decreases, and that the proportional heat loss increases with increase in the mean temperature of the charge. As applied to the aeronautical engine operating under reduced density conditions the results point to a relative increase in proportional heat loss to the walls as the machine ascends. Such condition corresponds to lower efficiency at altitude than on the ground, and this may be expected to effect either a reduction in power or an increase in petrol consumption or both, apart altogether from the direct influence of density upon charge weight and power output.

In the tests on engines 1 and 2, discussed in para. (1), the rate of decrease in power with decrease in density is lower in engine 1 than in engine 2. Both engines are identical in general design, except that the former is fitted with aluminium cylinders, while in the latter these are of cast iron. Independent tests show that the running temperature of the cylinders is lower in the former than in the latter. At a given density the mean charge temperature in No. 2 engine may therefore be expected to be greater than in No. 1 engine, and since the density effect upon heat loss has been seen to increase with increase in mean temperature, the difference in the performance of the two engines under reduced density conditions is probably attributable in part to this cause. With both engines the relationship between density and power is linear down to a pressure of approximately 70 per cent. of ground pressure, over which range the consumption remains sensibly constant. With densities lower than this, the power in each case diminishes more rapidly, while the consumption increases. The compression ratio at which No. 1 engine was tested was 4.7 : 1 and with No. 2 engine the ratio was 4.4 : 1. The volumetric efficiency of No. 2 engine is considerably lower than in No. 1 engine, due to structural differences in cylinder design in the two engines. As a result of this, at a given atmospheric density, the density of the charge prior to ignition will be somewhat lower in No. 2 engine than in No. 1 engine. The combined effect of higher charge temperature, lower compression ratio, and lower volumetric efficiency in No. 2 engine would therefore appear to produce conditions corresponding to greater proportional heat loss to the walls. The observed difference in performance of the two engines is not of large magnitude, as will be seen by reference to Fig. 2, but is of the order of the probable differences in charge density in the two cases.

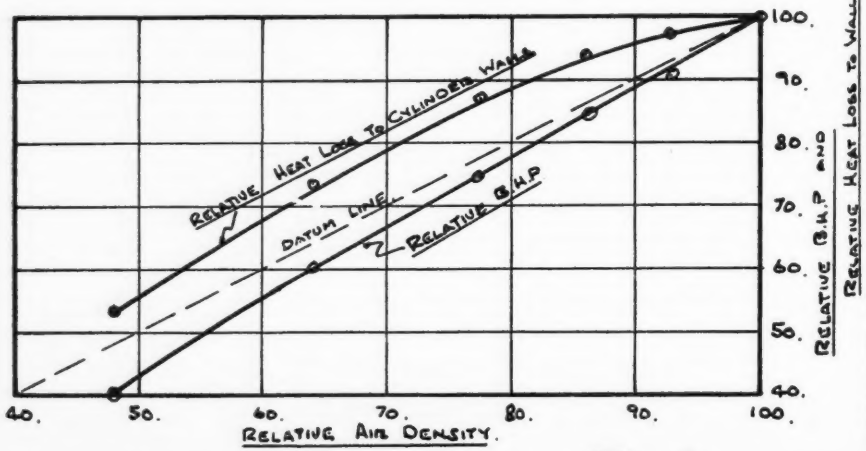


FIG. 8.

In the tests carried out on No. 2 engine, the temperature of the cylinders was measured by means of a series of thermocouples mounted in plugs screwed into the hottest part of the head. On the assumption that the heat dissipated by the cylinder cooling surfaces is proportional to the mean cylinder temperature—the cooling air temperature being constant, and that the mean temperature is proportional to the maximum temperature, the relative heat loss with varying air pressure is shown in Fig. 8.

The corresponding heat loss in the single cylinder Fiat tests is shown in Fig. 9. In both sets of tests it will be seen that the relative heat loss decreases less rapidly than air density, while the b.h.p. falls off more rapidly than density. The proportional heat loss, as represented by the ratio relative heat loss to

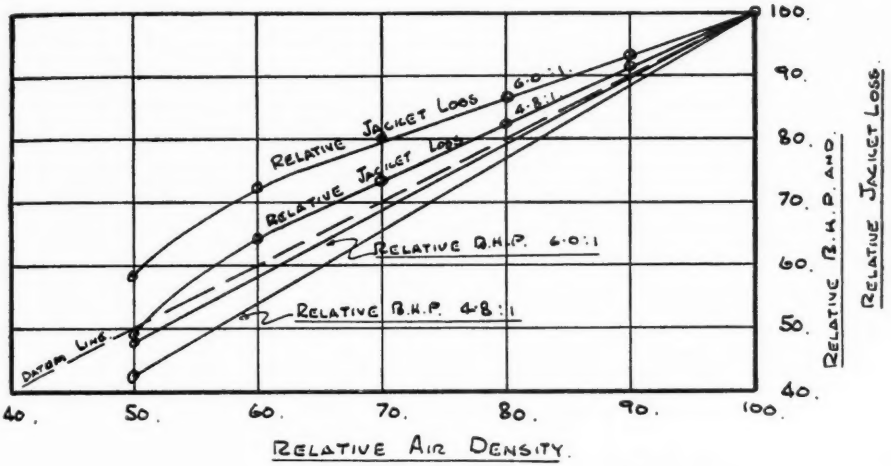


FIG. 9

relative b.h.p., therefore increases as the density diminishes. The observed diminution in relative heat loss at the lowest densities tested is evidently due to the cooling influence of the excess petrol in the charge. From Fig. 9 it will be seen that in the Fiat tests the proportional heat loss is slightly lower with the lower compression ratio which is contrary to what might be expected. This is however partly accounted for by the higher petrol consumption with the lower ratio—.56lbs./b.h.p./hour as against .52lbs./b.h.p./hour with the higher ratio.

In the Fiat tests the heat loss to the jackets varies approximately as $\rho^{\cdot 63}$ with the higher ratio, and as $\rho^{\cdot 87}$ with the lower ratio, where ρ is the atmospheric density. In the multi-cylinder air-cooled engine tests the mean value of the index of ρ is approximately .64.

In the Fiat tests increase in compression ratio was found to reduce the rate of decrease of b.h.p. with density, as discussed in para. (9). Corresponding to this, the mean petrol consumption per b.h.p. per hour decreased with increase in compression ratio throughout the range of pressures tested. With each ratio the petrol consumption per unit of power first decreases with decrease in density, attains a minimum value, and thereafter increases. The apparent explanation of this phenomenon would appear to be as follows:—Reduction in density entails increased proportional heat loss to the walls, and hence a constant rate of decrease in power involves increased consumption per unit of power. On the other hand,

with diminishing air density the b.h.p. and therefore the cylinder wall temperature decreases, and in consequence the petrol flow may be cut down to correspond more nearly to a mixture giving complete combustion, less excess petrol being required for internal cooling of the charge. The combination of these two effects will evidently result in the phenomenon observed. Similar results, though not so marked, were observed in the multi-cylinder engine tests.

It has already been observed that the density at which maximum thermal efficiency is attained decreases with increase in compression ratio.

The percentage density at which these maxima occur are approximately as follows :—

TABLE 13.

Compression ratio	4.8	6.0	7.6
Percentage of ground density at which maximum thermal efficiency developed ...	68%	60%	43%

The densities given above correspond roughly to the densities at which the compression pressure is the same with each ratio, a result which might be anticipated from the explosion vessel tests of Messrs. Bairstow and Alexander.

The Fiat temperature tests at air temperatures of + 13° C. and + 45° C. indicate that the rate of increase of consumption with diminishing density increases with increase in temperature. This substantiates the explosion vessel tests, which show the temperature effect on the heat loss to the walls to increase with diminishing density, a state of affairs corresponding to a reduction in engine efficiency.

While no direct inference as to the behaviour of petrol-air mixtures can be drawn from the tests of Messrs. Bairstow and Alexander, the points of correspondence between the engine tests and the explosion vessel tests would appear to indicate that the latter are qualitatively applicable to the working fluid in the petrol engine.

(13.) Power Recuperation at Altitude.

The lift of an aeroplane wing is given by $L = K_L (\rho/g) SV^2$ where K_L is the lift coefficient, ρ/g is the absolute air density, S is the wing area, and V is the air speed in miles per hour. The value of K_L varies with the angle of incidence. Assuming that the angle of incidence corresponds to that giving maximum value of the lift-drag ratio, conditions of maximum efficiency in level flight demand that ρV^2 shall be constant as the aeroplane ascends.

In an aeroplane of given gross weight a definite minimum speed exists below which horizontal flight is not possible. In commercial craft it may be taken that the rate of climb is subservient to conditions of maximum efficiency at the height at which the machine is designed to operate. Under these circumstances, so far as engine weight is concerned, maximum economy is secured if the motive power is such as to maintain the relationship.

$$V_h = V_g \sqrt{(\rho_g/\rho_h)}$$

Where V_h is the true air speed at the height h, and V_g is the minimum permissible air speed near the ground, ρ_h and ρ_g being the densities at height h and on the ground respectively.

Table 14 has been prepared to show the variation in horse-power absorbed and horse-power available in a typical case. The following data has been assumed :—

Aeroplane :—Gross weight of aeroplane 2,000lbs.
Wing section R.A.F. 15 aerofoil.
Wing area 250 sq. feet.

Engine :—300 b.h.p. on full throttle on the ground.
Airscrew efficiency 80 per cent. at all densities.
Variation in b.h.p. with pressure assumed to be the same as that of engine 3 of para. (1).
1 per cent. increase in power for each 10° C. drop in air temperature assumed.

With the above wing section, the lift-drag ratio is a maximum with an angle of incidence of approximately 3°. With this angle of incidence and with a gross load of 2,000lbs., the minimum speed in level flight near the ground is approximately 90 m.p.h. The relationship ρV^2 = constant is assumed.

TABLE 14.

Altitude in feet	0	5,000	10,000	15,000	20,000
Density relative to ground density	1.000	.855	.721	.617	.524
True vel. m.p.h.	90	97	106	115	124
H.P. absorbed	93	100	110	118	129
Thrust h.p. available	240	199	163	128	98

Comparison of the figures given for h.p. absorbed and h.p. available shows that up to a height of approximately 17,000 feet, the h.p. available is in excess of that required to maintain the machine in horizontal flight, the excess representing the h.p. available for climbing. At 17,000 feet the thrust h.p. is just sufficient to overcome the resistance to flight under the conditions specified, this being the maximum height at which level flight can be maintained.

The data given shows that if the machine is required to have a ceiling height of 17,000 feet, an engine capable of developing 300 b.h.p. on the ground is required, whereas the power absorbed in maintaining the minimum speed of flight near the ground is 93 h.p. Under the assumed conditions the machine is therefore considerably over-engined near the ground. If the machine were fitted with an engine developing 120 h.p. at the airscrew, and if means were adopted to maintain the power constant at all altitudes, the machine would still have a ceiling of approximately 17,000 feet. In this case, however, the excess of power available at any altitude up to the ceiling height is lower than in the previous case, and in consequence the maximum speed and rate of climb are lower. For commercial craft, and particularly for long distance service, the lower rate of climb obtainable with a light constant power engine would not appear to be a serious objection. The advantage of such an engine when operating at altitude is obvious.

In military scouting craft it is evidently desirable to secure the maximum possible rate of climb at all altitudes at which the machine is required to manœuvre, irrespective of the conditions of maximum economy outlined above. This necessitates the use of a power unit of much greater output than is required to maintain the minimum speed of flight. In such craft, any means adopted to recuperate the loss in power due to reduced density is evidently advantageous as effecting a reduction in engine weight for a given duty, or as affording a means of increasing the rate of climb or of adding to the ceiling height of the machine.

(14.) Supercompression as a Means of Power Recuperation at Altitude.

The test results discussed in para. (9) *et seq.* indicate the high relative merits of the supercompression engine when operating under the reduced density conditions obtaining at altitude, and suggest the possibility of recuperating the power loss in the normal engine by employing some means of increasing the compression pressure as the machine ascends. In practice two general methods are available.

(*a*) By employing a mechanism by means of which the stroke, and therefore the compression ratio, may be increased as the density diminishes.

(*b*) By permanent adjustment of the engine to give a high ratio of compression, the compression pressure being controlled by throttling from the ground up to that height at which the engine may be safely run on full throttle.

Variable stroke gear offers the best possibilities of realising the advantages of supercompression. As applied to the rotary or radial engine, the control mechanism is comparatively simple and the increased weight is not prohibitive.

In the Damblanc-Mutti variable stroke rotary engine, the master rod big-end is eccentrically mounted on the crank pin, the eccentricity being controlled by a hand-operated gear train. The range of compression ratio obtainable in this engine is from 4.8 : 1 to 7.0 : 1 and the weight of the engine together with the additional mechanism is 2.52lbs. per brake horse-power.

The application of variable stroke gear to the single line or multi-line engine would appear to be impracticable, due to the complication of mechanism involved, and in such engines a permanent adjustment of the compression ratio would appear to be essential. Where the engine is permanently adjusted to give a high ratio of compression, the charge weight may be reduced either by throttling at the carburettor or preferably by employing a stepped inlet cam so designed as to limit the compression pressure at all air densities in excess of that at which the engine is designed to run on full throttle. The fitting of stepped cams and control gear would add but little to the complexity of the mechanism of the normal engine, and the increased weight would be negligible.

(15.) The Effect of Throttling on the Performance of a High Compression Engine.

In the tests discussed in para. (9) *et seq.* the point at which detonation under full throttle conditions commenced was taken as the limiting pressure at which the engine could be operated on full throttle. An additional observation, corresponding to an increase of pressure of approximately two inches of mercury, could always be obtained by retarding the spark by approximately 5°, but further retardation resulted in a drop in power.

The limiting pressures and the approximate corresponding altitudes for each compression ratio are given below :—

TABLE 15.

Comp. Ratio.	Absolute Air Press. Inches Mercury.	Approx. Corres. Alt. in feet.	B.H.P. developed.
7.6 : 1	19.0	12,000	36
6.0 : 1	22.5	7,000	40
4.8 : 1	25.0	4,500	42

Tests were carried out with a compression ratio of 6.0 : 1 to determine the maximum power obtainable by throttling under ground conditions. In these tests the pressure on the exhaust side of the engine was maintained at that of the atmosphere. The disturbing influence of pressure oscillations in the neighbourhood of the jet, which accompanies the throttling of a single-cylinder engine, was minimised by connecting the carburettor to an air vessel of large capacity fitted with a throttle valve by means of which the pressure on the inlet side of the engine was regulated. The carburettor throttle remained full open throughout the tests. The results obtained may therefore be taken as substantially representing throttled conditions in a multi-cylinder engine. In each test the spark advance and petrol flow were adjusted to give maximum load. The results obtained are given in Table 16.

TABLE 16.

Absolute Pressure Inches of Mercury. Exhaust.	Induction.	Depression in Induction Pipe. ins. Mercury.	B.H.P.	Fuel cons. lbs./B.H.P. hr.	Spark Advce. Degrees.	Remarks.
	18.80	10.57	26.96	.618		
	20.97	8.40	32.62	.620		
	22.59	6.78	36.64	.743	35	
	23.61	5.76	39.00	.753		
29.37	24.57	4.80	41.50	.748		Slight Detonation.
	25.47	3.90	43.00	.700	28	
	25.47	3.90	43.00	.700	26	
	26.01	3.36	44.40	.705	25	Max. Possible Throttle Opening.

Comp. Ratio 6.0 : 1. Air Temp. 13.4°C. R.P.M. 1550.

Referring to Table 16 it will be seen that the depression in the induction system could be reduced to approximately 5in. of mercury before detonation with full spark advance commenced. Beyond this point it was found necessary to retard the spark in each successive test to prevent excessive detonation. Simultaneously, and for the same reason, it was found essential to increase the mixture strength as shown in column (5) A maximum brake horse power of 44.4 was developed with the spark retarded to 25°, *i.e.*, retarded 10° from its normal advance, with a depression in the induction system of 3.36 inches of mercury, and the petrol flow adjusted to give a consumption of approximately .705lbs. per b.h.p. per hour. Further, throttle opening on any mixture that would ignite resulted in overheating, severe detonation, and eventually in pre-ignition. In a similar series of tests carried out with a compression ratio of 7.6 to 1, the maximum power developed under throttled conditions was 37 b.h.p. with the spark retarded 10° and with the carburettor jet adjusted to give a consumption of .96lbs. per b.h.p. per hour. With this adjustment, running conditions were somewhat unsteady with a tendency to misfire.

Comparing the results obtained with those given in Table 15, it will be seen that with the 7.6 compression ratio the maximum power developed under throttled conditions on the ground, corresponds to the maximum power developed at the lowest altitude at which the engine can be safely operated on full throttle. With the 6.0 : 1 compression ratio considerably higher power can apparently be developed under throttled conditions on the ground. Quite generally it may be taken that a high compression engine when throttled on the ground will develop at least as much power (at constant speed) as it will develop at a given altitude on full throttle, and that this power can be maintained constant by increasing the throttle opening from the ground to that height at which the engine may be safely run all out.

From the above figures it will be realised that with a high compression engine the carburettor characteristic must be such as to meet throttled conditions on the ground and in climbing.

The maximum compression pressure that can advantageously be employed in any engine can only be determined by experiment. The present series of tests indicate that in the 300 h.p. Fiat engine the best compression ratio is probably in the neighbourhood of 6.5 : 1. With this compression ratio the engine, if throttled on the ground to prevent detonation, would probably develop a maximum b.h.p. sensibly equal to that of the normal engine and would maintain constant power up to an altitude in the neighbourhood of 10,000 feet. In this engine the position of the plugs is such as to give bad combustion conditions with compression ratios

higher than about 6.0 : 1. In an engine with the plugs situated in the head, much better results than those obtained are to be anticipated.

(16.) Effect of Fuel Composition on the Performance of a High Compression Engine.

As already discussed, the spontaneous ignition temperature of the fuel has a large controlling influence upon the extent to which the compression ratio of a petrol engine may be raised. Experience shows that under ground pressure conditions, the power output of an engine and its thermal efficiency, may be increased by the employment of a fuel of high spontaneous ignition temperature such as benzole or a mixture of petrol and benzole, in place of standard aviation spirit. The use of such a fuel in a high compression engine would appear to be advantageous in that the engine might be operated on full throttle at a greater air density than is permissible with standard spirit.

To investigate this point, tests were carried out on the single-cylinder Fiat engine at compression ratios of 6.0 and 7.6 : 1 on two fuels having a higher spontaneous ignition temperature than Shell Aviation Spirit. The density and calorific value of Shell Aviation Spirit and the two test fuels are given below.

Reference Letter.	Fuel.	Density.	Cal. Value B.Th.U.'s/lb.
A.	Shell Aviation.	.715	18.600
B.	20% Benzole + 80% Shell Aviation.	.745	18.300
C.	Cracked Fuel of the Olefine Series.	.707	18.600

The spontaneous ignition temperature of the three fuels was not determined, but it was known that (A) had the lowest and (C) the highest spontaneous ignition temperature of the series. The tests were conducted at constant temperature and over a pressure range down to approximately 10 inches of mercury. The results obtained are shown graphically in Figs. 10 and 11.

With both test fuels the gain in power as compared with standard spirit was found to be small, averaging 4 per cent. with fuel (B) and 2 per cent. with fuel (C) in both sets of tests at an absolute air pressure of 20 inches of mercury. At a pressure of 11 inches of mercury with the higher compression ratio, and at a pressure of 13 inches of mercury with the lower ratio, the power developed was identical with the three fuels. Pressures lower than the above-mentioned favoured standard fuel. The results obtained bear out previous experience in the testing of 30 per cent. benzole mixture on the test-bench and in flight, namely, that while this fuel gives considerably more power under ground conditions, in the air, any difference in performance between this and standard aviation spirit is within the limits of observational error. This is apparently due to the fact that the addition of any percentage of benzole to standard spirit raises the spontaneous ignition temperature of the fuel. Under full-throttle ground conditions, particularly with compression pressures higher than normal, the mixture strength with 20 per cent. benzole fuel can be reduced more nearly to that giving maximum power than is the case with standard fuel. With the latter, in order to prevent excessive detonation, it becomes necessary to increase the petrol flow to such an extent as to cause a drop in power. Under the reduced pressure conditions obtaining at altitude, the power developed is lower than under ground pressure conditions, the temperature of the cylinder walls is lower, and in consequence the temperature of the charge does not rise to such an extent as to cause detonation. Under such circumstances the spontaneous ignition temperature of the fuel, as an independent factor, has less influence than under full-throttle conditions on the ground.

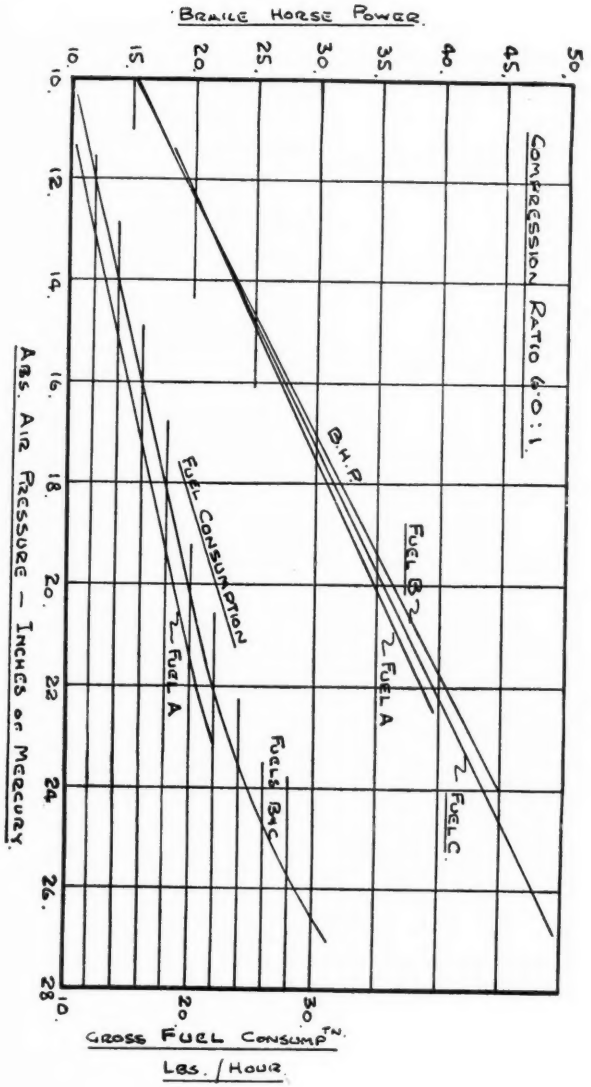

BRAKE HORSE POWER
10. 15. 20. 25. 30. 35. 40. 45. 50.
COMPRESSION RATIO 6·0 : 1.
B.H.P.
FUEL B
FUEL A
FUEL C
FUEL CONSUMPTION
FUEL A
FUEL B
FUEL C
ABS. AIR PRESSURE — INCHES OF MERCURY.
10. 12. 14. 16. 18. 20. 22. 24. 26. 28.
10 20 30
GROSS FUEL CONSUMPTN.
LBS. / HOUR

FIG. 10.

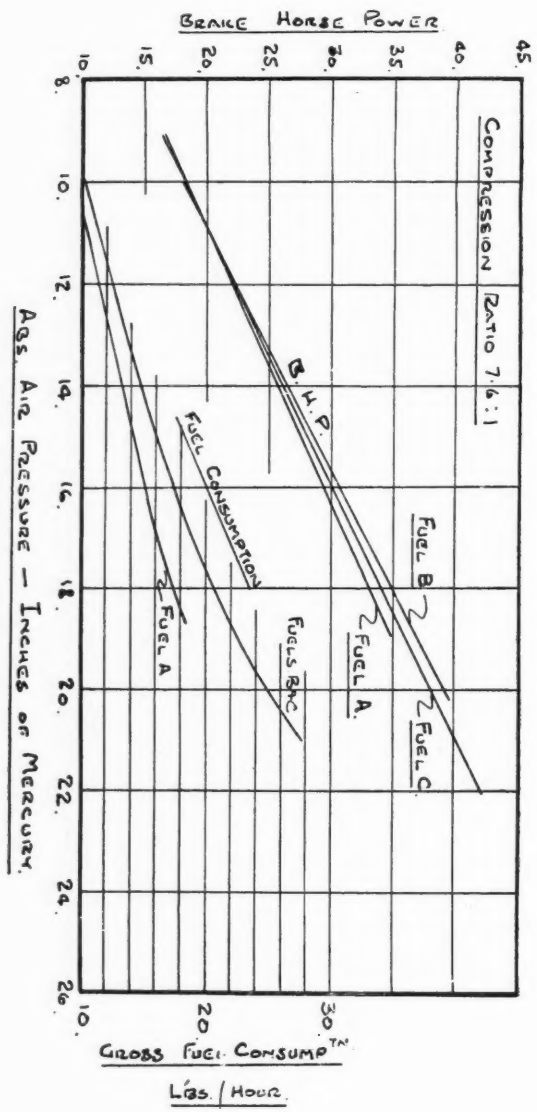

BRAKE HORSE POWER
10. 15. 20. 25. 30. 35. 40. 45.
COMPRESSION RATIO 7.6 : 1
B.H.P.
FUEL CONSUMPTION
FUEL B
FUEL A
FUEL C
FUELS B&C
FUEL A
8. 10. 12. 14. 16. 18. 20. 22. 24. 26.
ABS. AIR PRESSURE — INCHES OF MERCURY.
10. 20. 30.
GROSS FUEL CONSUMPTN
LBS. / HOUR.

FIG. 11.

Independent single cylinder tests on 20 per cent. benzole mixture showed that under full-throttle ground density conditions, an increase in power could be obtained by slightly increasing the spark advance with reference to its normal position for standard spirit. In the present series of tests, while this point was not specially investigated, no noticeable increase was obtained by increasing the spark advance under reduced density conditions.

The fuel consumption per b.h.p. per hour was found to be somewhat higher on fuels (B) and (C) than on standard spirit with both compression ratios and at all air densities over the range tested. The gross fuel consumed per hour under each test condition is shown in Figs. 10 and 11, while the heat loss to the jackets per b.h.p. per minute, and the fuel consumption per b.h.p. per hour with a compression ratio of 6.0 : 1 are shown graphically in Figs. 12 and 13. From Fig. 12 it will be seen that the consumption per unit of power is sensibly the same on fuels (B) and (C) and averages 10 per cent. higher than on standard spirit.

Throughout the range of densities tested, the heat loss to the jackets per unit of power was found to be lower with fuels (B) and (C) than with standard spirit. At pressures of 22, 18, and 14 inches of mercury the difference amounts to 36 per cent., 32 per cent. and 27 per cent. respectively. This is probably due in large measure to the difference in consumption as affecting charge temperature, and partly to a difference in the type of explosion with the different fuels.

The heat loss in the exhaust was not determined. It may be presumed, however, that the exhaust losses were relatively greater with fuels (B) and (C) than with standard spirit, due both to higher exhaust temperature and to a greater loss on account of unburnt fuel.

The heat distribution with the higher compression ratio is not discussed as with this ratio explosion conditions were abnormal as already indicated.

The limiting air pressure at which the engine could be operated on full throttle was found to be somewhat higher with both compression ratios on fuel (C) than on standard aviation spirit as indicated in Figs. 10 and 11. The benzole mixture occupies a position intermediate between standard aviation spirit and fuel (C). The following is an abstract of the results obtained showing the maximum b.h.p. obtained on each fuel.

TABLE 17.

	Comp. Ratio 6.0 : 1			Comp. Ratio 7.6 : 1		
Fuel.	Abs. Air Press ins. Mercury.	Correspond'g Altitude in feet.	B.H.P.	Abs. Air Pressure ins. Mercury.	Correspond'g Altitude in feet.	B.H.P.
A.	22.5	7,000	39.8	19.0	12,000	35.2
B.	24.0	5,500	45.0	20.0	10,000	39.2
C.	25.5	4,000	46.8	22.0	8,000	42.2

From the above it appears that fuels of high spontaneous ignition temperature are of value when employed in a high compression engine in that they permit of the engine being operated on full throttle at a greater density than is possible with standard fuel, and in consequence the thrust horse-power at the minimum permissible altitude on full throttle is increased. Assuming constant air speed, the relationship between the h.p. absorbed by the aeroplane and the maximum b.h.p. available on full throttle with the three fuels tested is as follows :—

TABLE 18.

	Comp. Ratio 6.0 : 1			Comp. Ratio 7.6 : 1		
Fuel.	Altitude in ft.	Relative h.p. abs.	Relative h.p. avail.	Altitude in ft.	Relative h.p. abs.	Relative h.p. avail.
A.	7,000	100.0	100.0	12,000	100.0	100.0
B.	5,500	106.6	113.3	10,000	105.3	111.3
C.	4,000	113.3	117.5	8,000	115.7	120.0

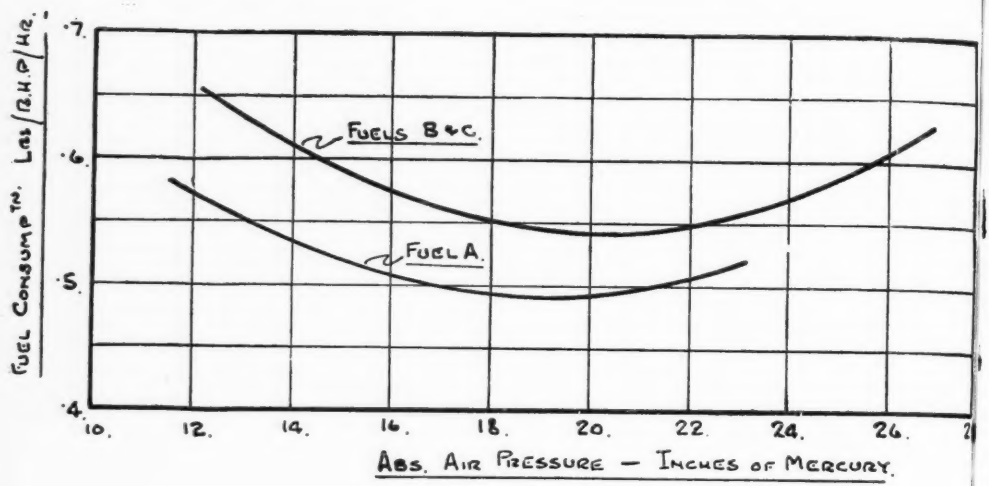

FUEL CONSUMPTN. LBS/B.H.P/HR.
·7
·6
·5
·4
FUELS B & C.
FUEL A.
10. 12. 14. 16. 18. 20. 22. 24. 26.
ABS. AIR PRESSURE — INCHES OF MERCURY.

FIG. 12.

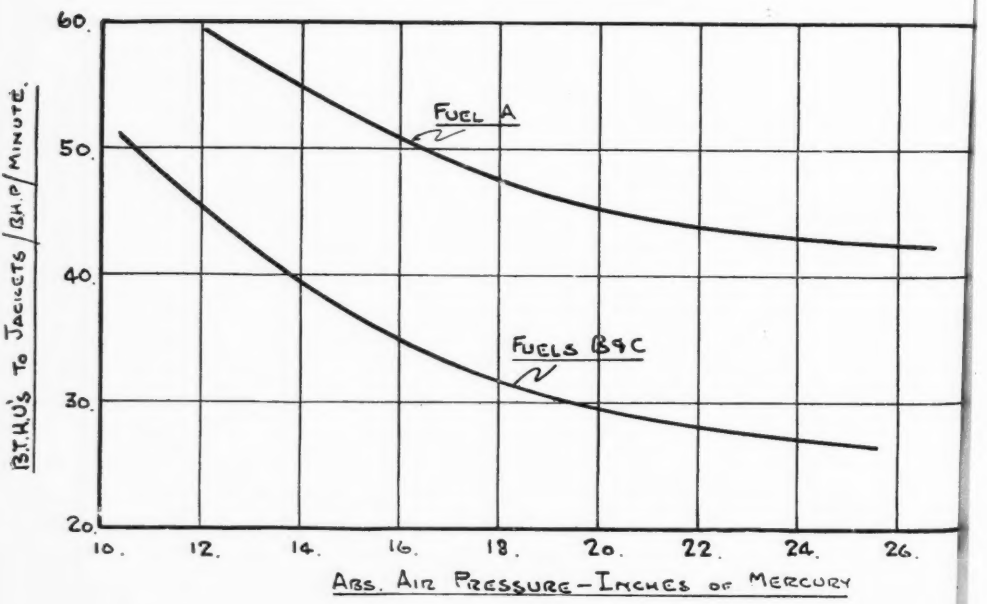

B.T.H.U'S TO JACKETS / B.H.P / MINUTE.
60.
50.
40.
30.
20.
FUEL A
FUELS B & C
10. 12. 14. 16. 18. 20. 22. 24. 26.
ABS. AIR PRESSURE — INCHES OF MERCURY

FIG. 13.

From the figures tabulated above it will be seen that the excess of power available with fuels (B) and (C) for giving increased speed, as measured by the difference between the h.p. available and that absorbed at the given speed, averages 6 per cent. with fuel (B) and 3½ per cent. with fuel (C). Fuels of high spontaneous ignition temperature offer the further advantage of increased horse-power with the engine throttled. With both fuels tested, the heat loss to the jackets per unit of power is some 30 per cent. lower than with standard spirit, giving a corresponding reduction in the size of radiator required. This is an important advantage, particularly as the cooling of a high-compression or super-charged engine is a matter of some difficulty.

Notwithstanding the above advantages it is improbable that the gain to be obtained by the use of an alternative fuel such as those tested would compensate for the increased fuel consumption.

(17.) The Cooling of Supercompression Engines.

(*a*) Water-Cooled Engines.

The quantity of heat dissipated by a radiator is proportional to $\theta\rho V^n$ where θ is the temperature difference between water and air, ρ is the air density, and V is the air speed.

The index n increases with air speed and has an average value of .8.*

If the machine climbs at constant indicated air speed, V varies as $\rho^{-\frac{1}{2}}$, and the rate of cooling is given by

$$K\theta\rho \cdot \rho^{-\cdot 4} = K\theta\rho^{\cdot 6}$$

The heat loss to the walls of an aero engine differs in different engines as discussed in para. (12), but may be taken to vary as $\rho^{\cdot 6}$. It is thus seen that θ is independent of density.

The boiling point of water diminishes with altitude due to reduction in pressure, the drop amounting to approximately 5°F. for each 8,000 feet increase in height. The drop in air temperature with increase in height is, however, slightly greater than this, and therefore compensates for the drop in boiling point. Taking the boiling point of water as the higher limit of temperature and the air temperature as the lower limit, the temperature difference between water and air available for cooling purposes is thus seen to be sensibly constant at all altitudes and approximately equal to 160°F. If, therefore, the radiator of a normal aero engine is sufficient to dissipate the heat given to the jackets under full-throttle conditions on the ground with the engine working at its maximum temperature, the cooling surface is adequate to meet the conditions obtaining at altitude.

In the super-compression engine the b.h.p. is maintained constant up to a definite altitude, beyond which the power falls off with diminishing density as in the normal engine. Under these circumstances the radiator must be of such a capacity as to dissipate the heat given to the jackets corresponding to the maximum output of the engine at the lowest density at which the full power is developed. The radiator of a constant power engine is therefore much larger than is required by a normal engine developing the same maximum power. The following figures have been deduced by Dr. A. H. Gibson as representing the necessary increase in radiator surface in such an engine developing constant power up to the altitudes shown.†

* Professor A. H. Gibson, D.Sc., M.Inst.C.E., M.I.Mech.E. Advisory Committee for Aeronautics, I.C.E. Report No. 407.

† Advisory Committee for Aeronautics, I.C.E. 121.

TABLE 19.

Engine Developing Constant Power up to	Percentage Increase in Radiator Size.
6,000 feet.	40%
9,000 feet.	55%
12,000 feet.	70%

The relative importance of the size and weight of the radiator can only be adequately discussed in relation to the resistance of the aeroplane and the resistance of its accessories, the gross weight carried, etc., etc. Under certain circumstances increase in radiator weight and resistance to the required extent might prove prohibitive.

(*b*) Air-Cooled Engines.

In the water-cooled engine the permissible range of wall temperature is not determined by the limiting temperature at which the cylinder, as such, is capable of operation, but is rather governed by the efficiency of the jackets, the capacity for heat absorption of the jacket fluid, and the cooling capacity of the radiator. In flight the radiator must be of such a size as to maintain the temperature of the jacket fluid below its boiling point under the varying conditions encountered. In a water-cooled engine boiling of the jacket fluid not only gives rise to bad circulation but also leads to loss of water.

In the air-cooled engine no such restrictions obtain, the engine being capable of efficient operation over a wide range of wall temperature. The following table shows the variation in maximum cylinder wall temperature with increasing altitude in an aluminium air-cooled engine designed to maintain constant power up to the various altitudes given. The figures have been deduced by Dr. A. H. Gibson from results obtained on a normal engine tested in flight.*

TABLE 20.

Altitude in feet.	Max. Cylinder Temp. °C.
2,500	160
6,000	170
9,000	181
12,000	193

The data given is based on the assumption that the cowl is identical in each case, and that the machine climbs at constant indicated air speed. Bench tests carried out on the engine to which the above figures refer showed this to be capable of efficient operation with a maximum wall temperature as high as 220°C. As a power-recuperating unit the air-cooled engine offers the great advantage of improved aeroplane performance at altitude without materially increasing the weight and resistance of the power plant and its accessories. With the water-cooled engine maintenance of power with diminishing density involves increase in the weight and resistance of the radiator as already discussed. The air-cooled unit offers the further advantage of immunity from freezing at high altitude.

(18.) Airscrew Torque and Speed.

The efficiency of an airscrew at a given density decreases with increase in speed of revolution. Under reduced density conditions, for constant efficiency in level flight at various altitudes, the airscrew speed should vary in accordance with the relationship $\rho n^2 = \text{constant}$. Assuming a ground speed of 1,200 r.p.m. on

* Advisory Committee for Aeronautics, I.C.E. 121.

full throttle, the speeds of revolution corresponding to constant efficiency at various altitudes are given in the second line of Table 21.

TABLE 21.

Altitude in feet ...	0	5000	10000	1500	20000	25000	30000
Airscrew R.P.M. ...	1200	1300	1410	1526	1650	1810	1990
Engine Brake M.E.P. lbs. per sq. inch :—							
Normal Engine ...	108	92	77	61	51	40	31
Constant Power to 10,000ft.	108	109	110	89	73	58	46
Constant Power to 30,000ft.	108	109	110	110	110	109	108

In order to maintain the relationship ρn^2 = constant, the applied torque, and therefore the brake mean effective pressure of the engine, must be constant over the speed range indicated.

The variation in brake mean effective pressure with speed differs widely in different engines, being dependent upon cylinder design and particularly upon valve size and disposition. An examination of a considerable number of aero engine power curves shows that on full throttle the variation of torque with r.p.m. over the working range of speed varies from 5 per cent. to 15 per cent. of the mean torque. In certain engines the variation is, however, considerably lower than this. In an experimental engine tested by the Author the brake mean effective pressure developed at various airscrew speeds was as indicated in the last line of Table 21. The figures given show the variation in torque with speed in this case to be only 1 per cent. of the mean torque over a speed range from 1,200 to 2,000 r.p.m. If such an engine were capable of constant power development at all altitudes, ρn^2, and therefore the airscrew efficiency, would be sensibly constant.

The variation in brake m.e.p. with altitude if the power were maintained constant up to 10,000 feet is shown in line 4 of Table 21, while the figures given in line 3 refer to the normal engine.

In the normal aeroplane power plant the airscrew is designed to give the highest overall efficiency under the average conditions of flight. The figures given in Table 21 show that with a suitable speed characteristic the constant power engine enables the maximum overall efficiency of the aeroplane to be more nearly approached than does the normal engine. While this is so, it is to be realised that for the same maximum power the constant power engine gives the machine a much wider range of flying speeds than the normal engine. If the full range of flying speeds is demanded, the constant power engine will evidently necessitate the use of a variable pitch propeller or some such device as will maintain the speed within the limits for which the engine is designed.

(19.) Aeroplane Performance with Constant Power Unit.

In the normal aero engine cylinder of the usual stroke bore ratio the maximum possible compression ratio is dependent upon cylinder head and piston design as effecting the minimum permissible clearance volume. In all present-day aero engines a maximum compression ratio between 6.5 and 7.5 to 1 is readily obtainable by the use of high-compression pistons, and where the sparking plugs are located in the head, ratios higher than this are quite practicable. The tests discussed indicate the possibility of maintaining constant power from the ground up to a height of approximately 10,000 feet with a maximum compression ratio between 6 and 7 to 1. Assuming that this represents the practicable limit to

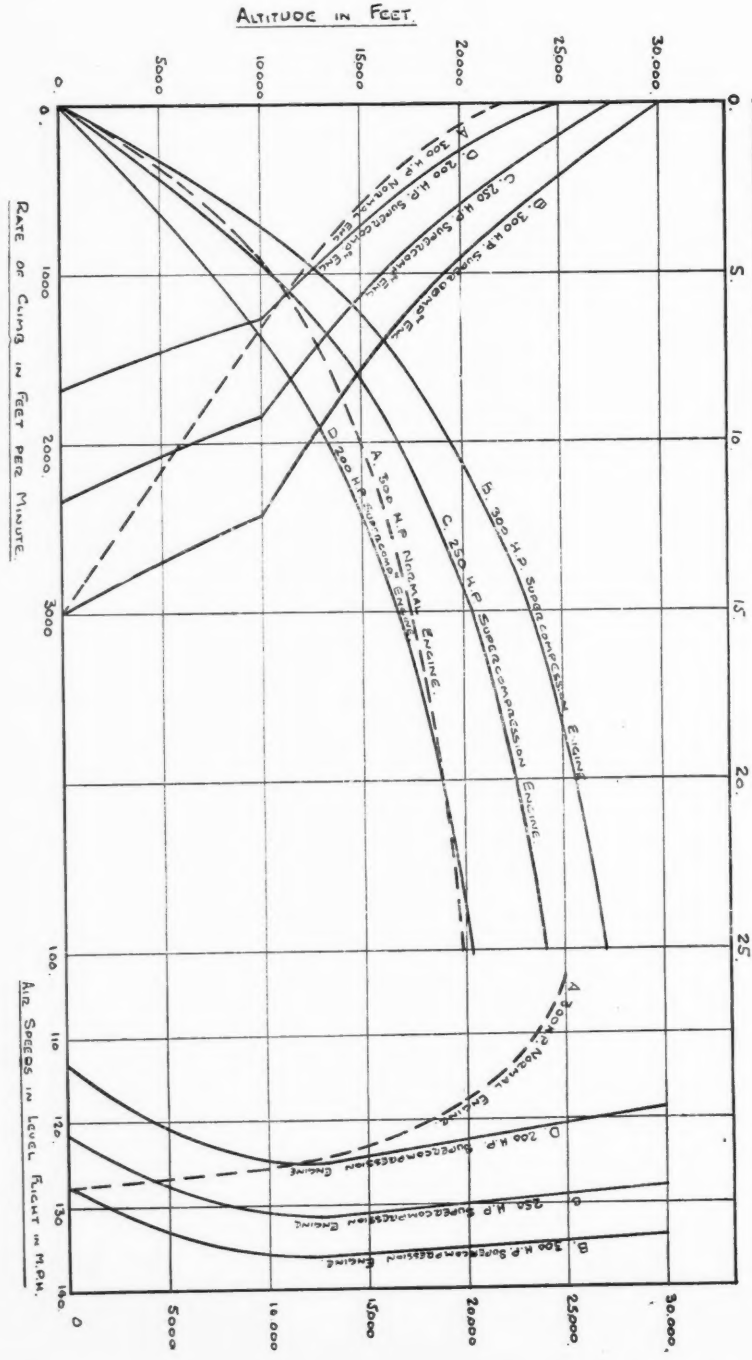

Altitude in Feet
Time in Minutes to Reach Various Heights.
Rate of Climb in Feet per Minute.
Air Speeds in Level Flight in M.P.H.
A. 300 H.P. Normal Engine
B. 300 H.P. Supercompression Engine
C. 250 H.P. Supercompression Engine
D. 200 H.P. Supercompression Engine

Fig. 14.

the use of high compression, the curves of Fig. 14 have been prepared to show the probable performance of the aeroplane exemplified in para. (13) with various engines. The curves shown in Fig. 14 refer to the following conditions :—

CURVES A.—Normal engine developing 300 b.h.p. on the ground.
CURVES B.—Engine of 300 b.h.p. developing constant power up to 10,000ft.
CURVES C.—Engine of 250 b.h.p. developing constant power up to 10,000ft.
CURVES D.—Engine of 200 b.h.p. developing constant power up to 10,000ft.

In each case a constant airscrew efficiency of 80 per cent. has been assumed, and the speed of climb has been taken as 75 m.p.h. near the ground, increasing with increasing height in accordance with the relationship $\rho V^2 = \text{constant}$.

From the plotted results it will be seen that with the 200 b.h.p. power recuperating engine the ceiling height is somewhat greater than with the 300 b.h.p. normal engine, while the time taken to reach the ceiling height is nearly the same in each case. This is due to the fact that while the rate of climb up to approximately 10,000 feet is lower with the former than with the latter, it decreases less rapidly, due to the maintenance of constant power up to 10,000 feet, and to the fact that at altitudes above 10,000 feet the high-compression engine is affected to a lesser degree by reduction in density than the normal engine.

Assuming that engine weight is directly proportional to the maximum b.h.p. developed, the saving in weight is seen to be approximately 30 per cent.

Comparing curves *A* and *B* it will be observed that the maintenance of constant power in the 300 h.p. engine up to a height of 10,000 feet, increases the ceiling of the machine by approximately 36 per cent. as compared with the normal 300 b.h.p. engine. The maximum speed of the aeroplane in level flight at various altitudes with the two engines is as follows :—

TABLE 22.

Altitude in feet	5,000	10,000	15,000	20,000	25,000
300 h.p. normal engine	127	126	123	118	—
300 h.p. power recuperating engine	133	136	136	135	135

The increased air speed, together with the increased rate of climb and the improved ceiling of the aeroplane obtainable with the power recuperating engine, indicates clearly the possibilities of such an engine, particularly as applied to military and long-distance commercial craft.

(20.) Conclusions.

The investigation leads to the following general conclusions :—

(*a*) The performance of an aero engine under the conditions obtaining in flight, as measured by the rate of decrease of power, and the variation in fuel consumption, with diminishing density, is dependent upon engine type and cylinder design. The factors which limit the power output and thermal efficiency of an engine have a relatively greater effect at altitude than on the ground.

(*b*) In the aero engine, a high degree of compression is essential. The rate of decrease in power with decrease in density, and the petrol consumption per unit of power, decrease with increase in compression ratio.

(*c*) The tests results given establish the possibility of super-compression as a means of power recuperation at altitude. In the super-compression engine, constant power is maintained without undue complication of mechanism, and with

no sensible increase in engine weight. The data discussed points to the superiority of air cooling as against water cooling in a power recuperating unit.

The Author takes this opportunity of expressing his indebtedness to the Director of Research of the Air Ministry for permission to publish the experimental results upon which the above discussion has been based, and to Professor A. H. Gibson, D.Sc., M.I.C.E., M.I.Mech.E., of Victoria University, Manchester, for his kindness in allowing the Author to refer to much of his published and unpublished work.

REVIEWS

The Case-Hardening of Steel. By Harry Brearley. (Longmans, Green & Co.) 16/- net.

The Author is to be congratulated upon the second edition of this very useful book. The various chapters will be found to constitute a reliable guide in practice for those interested industrially in the art of case-hardening. The theoretical principles are well explained, but what is almost more important is the general handling of the subject from the practical point of view. The illustrations are numerous and well chosen with a view to illustrating the various points dealt with in the text.

The book is divided into eleven chapters, each dealing with some different aspect of case-hardening. Chapter II., dealing with the structural changes, is well done and should be very carefully studied. Chapter X., dealing with hardening and tempering of steel, is also very well done, and contains many observations which are the result of practice and, no doubt, costly experience at one time or another. In Chapter IX. the Author deals with the various steels available for automobile construction, and the addition to this edition will no doubt be welcomed. It is surprising that in dealing with automobile steels the Author has not seen fit to include the 12/14 per cent. chromium steel which is so valuable for its rust and stain resisting properties and for which there must surely be a considerable future in the automobile and aero industry.

W. H. H.

Aeroplane Performance Calculations. Harris Booth. (Chapman & Hall, D.U. Technical Series.) 21/-.

In common with most engineering calculations, the estimation of the performance of an aeroplane involves assumptions of doubtful accuracy. The doubts arise from two causes: (1) absence of the precise experimental results required, (2) conflict among such experimental results as bear upon the point. In his endeavour to live up to the title of the series in which his book is published, Mr. Booth refrains not only from indicating where the doubts lie, but also from discriminating between the two varieties. He makes amends by definite statements (*e.g.*, pp. 4, 96, 97), but omits to give references which might enable the intelligent reader to check them. Such a course may be "directly useful," but it cannot fail to leave an unhappy impression on the reader who has any previous knowledge of the subject. To this extent the sufferer is Mr. Booth, though no small part of the real responsibility lies on the inventor of the pernicious title of this "directly useful" series.

But another class of reader will not escape unharmed—the draughtsman anxious to improve his standing in his profession. For his sake, since this and other similar books make a special appeal to him, the warning must be given that only an expert can discriminate between what is good in the book and what is untrustworthy.

A large part of the book is, in effect, an elaborate sliderule. No errors of consequence have been detected, and where the reader is attracted by any of the methods described, he can safely use the graphical or tabular schemes suggested. One cannot refrain, however, from expressing the opinion that tabulation is not an exact science, and what appeals to Mr. Booth as *the* way may not impress another. Few things are harder to grasp than another man's tabular work.

Some technical points require remark. The method recommended (p. 9) for dealing with an unknown body—to take the nearest "perfect" shape and add cockpits and windscreens at so many pounds each—is unlikely to yield good results. Tailplanes are dealt with as if they were merely, say, fins, regardless of the fact that, owing to downwash, a tailplane may have, and often does have, a negative resistance. The three-page treatment of wing characteristics is hardly commensurate with the importance of the subject.

The whole treatment of engine power is very confusing, and the precise difference between P_r (engine power at full revolutions) and P_t (engine power at full torque) is nowhere made clear. The assumption that friction power/indicated power = .262 for rotary engines and .161 for stationary engines, without a word of explanation or reference, is typical of the book.

The get-up of the book is excellent, the type and paper good, and a model index is provided.